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CONTENTS

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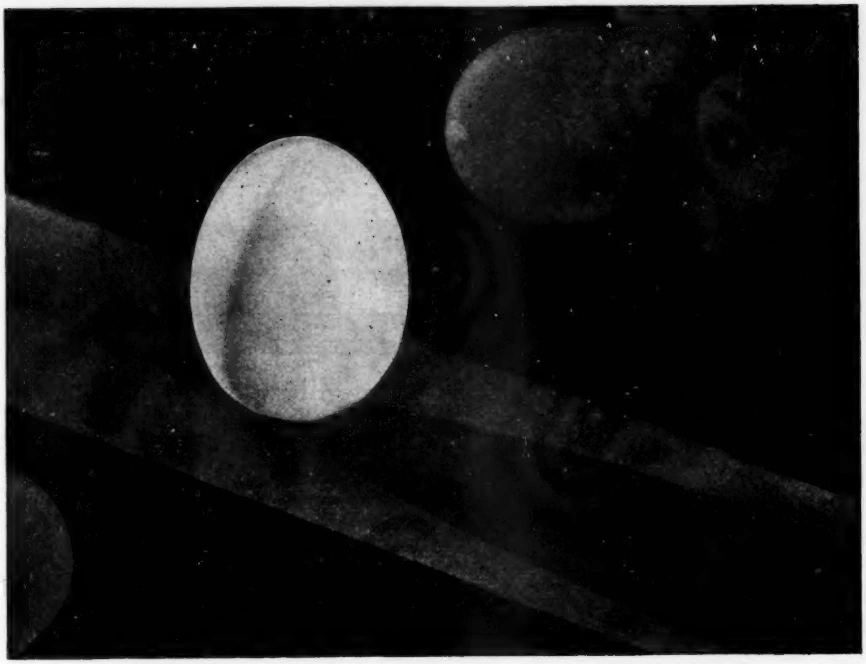

Articles for July *Bulletin*

Present Tectonic State of the Earth
By Hans Stille

Geology and Bitumens of the Dead Sea Area, Palestine and Transjordan
By Frederick G. Clapp

Geosynclinal Boundary Faults
By W. A. Ver Wiebe

Present Oil Supply in California
By Harold W. Hoots

Preliminary Report on the Fitts Pool, Pontotoc County, Oklahoma
By Don L. Hyatt

BULLETIN ADVERTISERS

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JUNE, 1936

MARINE UNCONFORMITIES, MARINE CONGLOMERATES, AND THICKNESSES OF STRATA[1]

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ABSTRACT

The deposition of marine gravels is examined from the points of view of the places of deposition, the depths of water, and the relation of the sites of deposition to sea-level. In connection with the problem an inquiry is made with respect to the possible thicknesses and extents of marine gravels and the possibilities of transportation of gravels into deep water.

An examination is made of the conditions that control in the development of unconformities beneath marine deposits and it is pointed out that unconformities may readily develop under submarine conditions. Some criteria for the determination of unconformities that develop beneath the sea are presented.

Lastly, there are considered the factors upon which thicknesses of deposits, particularly marine deposits, depend, and it is shown that under some conditions a given stratigraphic unit may range from zero to many hundreds and even thousands of feet. It is concluded that measurements of time based on thickness of deposits have little value.

INTRODUCTION

Current explanations of marine gravels (conglomerates) and marine unconformities are that such are connected with changes of sea-level—an invasion of the land by the sea following a negative movement of the land, or a relative rise of sea-level due to other causes; that an unconformity beneath marine deposits is accompanied by a greater or less thickness of gravels at the base of the overlying strata; and that the unconformity was produced by an invasion of the sea over the land. From the opposite point of view, there is a

[1] Presidential address, Society of Economic Paleontologists and Mineralogists, read before the Association at Tulsa, March 19, 1936.

[2] Department of Geology, University of Wisconsin.

general assumption that the occurrence of gravels (conglomerates) beneath marine strata indicates an unconformity, a stratigraphic break, and a land interval. While these assumptions are not completely acceptable to all geologists they yet seem consciously or unconsciously to pervade the thinking of many, they frequently are given dogmatic statement in geologic literature, and there are few textbook illustrations of an unconformity that do not show sands and (or) gravels immediately upon it, usually the latter.

Another common assumption that is frequently made and an assumption that unconsciously enters the thinking of most of us is that the thickness of strata is a measure of the time involved in deposition. Furthermore, this assumption is ***probably correct for each minor sedimentary unit representing continuous deposition***. The error arises when an attempt is made to assign a value to the unit in terms of time, since, except in a very few cases, no data are known that make it possible to state a general or an average time value for any deposit. The error is magnified when anything assumed for any particular, very minor unit is carried to some other unit in the same or some other section and ultimately to an entire section.

On the basis of sedimentation and stratigraphy no one is in a position to evaluate with any hope of correctness the length of time involved in the deposition of any unit other than those that are demonstrably varved and possibly the bentonite and metabentonite beds in different parts of the geologic column. The thickness of a stratum and the thickness of a section are certainly expressions of the times involved, but the rates of deposition in shallow waters of modern seas vary from day to day and from year to year, with a range from zero to several tens of feet per annum. Such must have been equally true in the past and each small unit of a geologic section is almost certain to have had a rate of deposition different from any other. It seems hopeless to expect that an average rate will ever be found. The rates of deposition of sediments are known in only a few instances, and in only a few places and even after the rate of deposition for any particular type of sediment deposited in any particular place at any particular time is determined, he indeed is rash and not in full appreciation of all the limitations, who attempts to apply that rate to the same type of sediment deposited at another place or at another time, and certainly extremely rash if the attempt is made to apply the rate to any other sediment no matter how slightly different. The writer agrees with Schuchert[3] "that as yet there is no known mean rate of deposition, and also none for sandstone, shale, or lime-

[3] *U. S. Nat. Res. Council Bull. 80* (1931), p. 36.

stone. Furthermore it appears . . . that a mean applicable to all strata at all places can never be ascertained;" but he does not agree that "all that can be expected is a mean for each deposition basin." This is also considered a vain hope.

One of the responsibilities and also one of the privileges of a geologist—and, it may be added, of any scientist—is the constant questioning of old concepts and assumptions to determine the extent of their application and validity. The writer proposes to do this at this time with respect to the occurrence of gravels (conglomerates) in marine deposits, the relations of marine gravels (conglomerates) to unconformities, the occurrence of unconformities beneath marine deposits, and the thickness of deposits. The problems to some extent have been considered by the writer in other connections, but this is his first attempt to focus attention directly upon the phenomena and their relations. The examination will be directed along channels as follows: (1) environmental conditions leading to the deposition of marine gravels (conglomerates); (2) conditions that control during the development of a surface destined to become an unconformity beneath a marine deposit; (3) unconformities beneath marine deposits; and (4) factors determining thickness of deposits. These will be considered in the order given.

ENVIRONMENTAL CONDITIONS LEADING TO DEPOSITION OF MARINE GRAVELS (CONGLOMERATES)

Marine gravels are defined as those deposited in the sea or in bodies of water more or less closely connected with the sea. These are the gravels of the littoral and neritic zones, the gravels deposited in bodies of water like Hudson Bay and the Baltic Sea, and in the epicontinental and epeiric seas of the past, irrespective of whether the waters of deposition were fresh or salt. Such are the gravels present on numerous horizons in the 2,400-foot section of the Silurian and Ordovician of Anticosti Island, those at the base of the Mingan formation of the Mingan Islands section, those in the Silurian (perhaps in part Ordovician) section of Newfoundland, those at the base of the Trempealeau formation and at several levels in the Jordan member of that formation in the Upper Cambrian of the upper Mississippi Valley, the gravels locally present at the base of the Glenwood member of the Platteville formation of the same region, and there are many others. Some of these gravels are associated with unconformities but so far as known those in the Anticosti section and those in the Jordan member of the Trempealeau formation have no relation to an unconformity.

There are many variable conditions or factors that bear on the deposition of marine gravels. Those here considered are places of deposition and depths of waters, erosive and transporting powers of waves and currents, and characters of the adjacent coasts and lands. An inquiry is also made with respect to possible thickness of marine gravels.

Places of deposition and depths of water.—It may be assumed that most marine gravels are deposited in the littoral and neritic zones, but the fact that large rock fragments may be deposited on any bottom from floating ice, trees, and sea weeds must not be overlooked. Deposition from floating sea weeds and trees on bottoms far from land could be only occasional and could account only for sporadic occurrences of large rock fragments, but sea weeds may have considerable importance in scattering large rock fragments over neritic and bathyal bottoms not far from land, or around shallow areas in the deep ocean on which sea weeds live and grasp rocks in their holdfasts. Deposition of gravels and larger fragments from floating ice may concentrate sufficient pebbly, gravelly, and bouldery material over restricted areas of any bottom to give rise to deposits of which the large particles may constitute a considerable and perhaps the major portion; and if such bottoms were washed by currents competent to carry away the fine sediments, the coarse materials might ultimately dominate on the bottom. In general, deposition of coarse clastics on abyssal bottoms and on the lower one-half to three-fourths of the bathyal bottoms may be disregarded, as a considerable quantity of large fragments on such bottoms would be likely to be only local and occasional. Deposition of gravels on bathyal bottoms, particularly on the upper one-fourth to one-half, is likely to have considerable importance where such bottoms approach close to land, as is the case around many of the islands of both the East and West Indies, the Philippines, Japan, and many oceanic islands. Deposition on such bottoms is favored by rapid increase in depths outward from the shore and such increases are not rare in the regions cited.

Under conditions of stationary sea-level there may be considerable accumulations of gravel in the littoral zone if the materials of the shore can supply gravel, if the adjacent waters are deep enough to develop effective wave action to derive them from the shore, but not so deep that all shore-derived materials immediately sink to depths unaffected by wave and current action. If the littoral is bordered by water of depths in which large waves may develop, the coarsest constituents stay with the beach, for the simple reason that the outgoing waters are not strong enough to remove them, the minimum dimen-

sions of the remaining materials varying with the strengths of the outgoing currents. The coarsest constituents remain with the beach until they are reduced to sufficient smallness for the outgoing currents to carry them away, the dimensions of the particles thus carried away depending on the competencies of the outgoing and shore currents and the shapes and specific gravities of the particles, those of lowest specific gravity and with two or more equal diameters being transported most readily. Strong waves and currents may transport gravels and boulders shoreward beyond the reach of ordinary waves and currents to build littoral barriers, but such constructions are temporary, and on a shore subject to erosion, soon destroyed and removed. Under any conditions, the accumulation of littoral gravels at any place can not attain a great thickness, perhaps under ordinary conditions 20 feet as a maximum, and these gravels will rest on the landward margin of a wave- and current-cut surface sloping gently seaward from a little above low tide level at the shore to a few feet below that level on the seaward margin. These gravels are more or less well rounded but it should not be assumed that this is invariably true, since the gravels of some beaches exhibit little rounding. As the sea erodes inland the coarsest sediments migrate inland leaving behind a rock floor bare of deposits; the transportable materials within the competency of the outgoing currents have been moved outward across the eroded surface to be deposited on neritic bottoms and perhaps on the upper parts of bathyal bottoms, particularly if descent to the latter is relatively rapid, or they may have been carried along the shore. The gravels are thus limited to a narrow belt in the littoral, none being present on any part of the wave- and current-cut rock floor except adjacent to the littoral, and beyond this rock floor in a relatively narrow belt on neritic bottoms and perhaps on the upper parts of bathyal bottoms. The wave- and current-transported gravels on neritic and bathyal bottoms may be expected to have a rather high degree of rounding.

With rising sea-level, under conditions of a not too ample supply, the coarsest materials also remain and move with the beach unless rise of sea-level is extremely rapid, a matter of tens of feet in a few years—probably a rather rare occurrence,—under which conditions they may be left behind by the invading waters. Ordinarily a wave- and current-cut rock floor is produced in the same manner as under the conditions of stationary sea-level, differing only in that it has a somewhat greater slope seaward, this slope being coördinated with the rise of sea-level, and, in general, being of low angle. Deposits would be made on the seaward margin of this rock floor as it became

sufficiently deeply submerged to permit permanent deposition. These deposits would have a coarseness determined by the competency of the outgoing waters and would have rounding commensurate with the extent of transportation.

In each of the foregoing cases no beach may be present in the beginning. Under such conditions materials would accumulate near the shore to build a beach, following which the development would proceed as already indicated. The materials may range from coarse to fine clastics.

There is still a third condition—that of falling sea-level. A deposit of gravel may be made over the surface released by the sea. In most cases it is thought this will be in the form of successive windrows of gravel rather than as a blanket of somewhat uniform thickness. These gravels become the surface of the land and thus will be subject to the various influences that may act upon them under such conditions. They may be covered only in regions adjacent to the mouths of rivers and hence are relatively unimportant. Should the sea advance, they would be subject to the fate already described.

The two conditions of stationary sea-level and rising sea-level with the shore moving inland, under the first condition, because of erosion alone; and, in the latter case, because of erosion assisted by rise of sea-level, give different results.

With stationary sea-level, the materials of the shore are transported outward across the wave- and current-cut rock floor. They have a coarseness commensurate with the competency of the outgoing waters, and are deposited on those deeper bottoms over which the transporting power is reduced, becoming finer with distance from the source. The places of deposition will have depths and distances from the shore depending upon the competencies of the waves and currents, and each successive deposit will outlap, or overlap outward, the immediately previous deposit which, in general, may be expected to be composed of smaller particles than the succeeding. As competencies vary from time to time and with different distances from the shore, there result, at each place outward from the shore, deposits of varying degrees of fineness or coarseness in the vertical section. Thus, at one time the competencies may be such as to transport to a given place clays and silts only, at another time sands, at another pebbles, and, under occasional conditions, materials of dimensions larger than sands and pebbles, each place outward from the shore at any time having its own particular characteristic deposit based on competencies. As the competencies likewise vary parallel with the shore there is lateral gradation with respect to texture in every direction to a

greater or less extent and *it should be axiomatic with every sedimentationist and stratigrapher that any marine clastic deposit may be expected to grade laterally either into another clastic deposit of some other degree of texture or into a deposit of different lithology.* As the bottom is built upward to the base level of deposition (base level of erosion, profile of equilibrium), the shoreward part of the deposit reaches this level first so that this shoreward part becomes a surface over which additional sediments are carried seaward. Only the shoreward margin of these deposits could have any relation to an unconformity and for the successive layers of gravels that may be interbedded with finer varieties of clastic deposits there would be no such relation whatever. If sea-level should rise, the surface of the base level of deposition would receive deposits which would have unconformable relationships with those below and the overlying deposits would not necessarily be gravels but might *rest on gravels at the top of the underlying strata.*

Under conditions of rising sea-level, the outer or seaward margin of the wave- and current-cut rock floor receives deposits as it progressively becomes sufficiently deeply submerged. The initial deposits at any particular place are progressively covered or overlapped by other sediments which may be expected to be, in general, of finer texture, or, in some cases, not clastics but carbonates. It must not be forgotten, however, that because of the varying competencies from time to time an interbedding of finer and coarser materials will result as the deposits are made and that the changes in texture can not be indicated by a straight line, but by an undulating one with a trend to finer texture upward.

Should the periods of rise of sea-level be interrupted by periods of stationary sea-level of long duration, there would be a combination of the two results—a building outward during the times of stationary sea-level, and a building inward over the rock floor with rise of sea-level. Under conditions of a rising sea-level, the rock floor may be overlain unconformably by coarse deposits, but, on the other hand, the sediments may be as fine as clays and silts and they may also be carbonates. Any surface developed to the base level of deposition under conditions of a stationary sea-level would require rise of sea-level before this surface could receive deposits and become an unconformity. Conditions would determine the character of the basal strata above the unconformity.

Thus there are two contrasted conditions: one under which the sediments migrate outward or outlap over finer deposits as the bottom is built to the base level of deposition, with the deposits in any section

progressively coarser upward as the bottom is built nearer to that level, but with interbedding of materials of various degrees of fineness or coarseness due to varying competencies from time to time; and the other under which the deposits extend progressively farther landward to rest at the edges on the wave- and current-cut surface, with finer deposits progressively deposited over coarser as a result of gradually increasing distances of the places of deposition from the shore, so that the section *at any one place progressively passes into finer deposits upward* although there is still interbedding of finer and coarser sediments. No commitment can be made with respect to degree of fineness or coarseness except that under some conditions of wave and current competencies the coarseness at one extreme will be of the order of magnitude of clays and silts and under others perhaps of cobbles or larger dimensions. The dimensions in all cases are consonant with those depths, slopes of the bottom, and distances from the shore over and to which the waves and currents have effective transporting power. The deposition under both conditions will be largely in neritic waters, but under conditions of steep bottom slopes, the gravels and other deposits may be moved outward to the upper parts of bathyal bottoms provided such are not too far distant from the shore. With rising sea level bathyal bottoms recede from the shore, thus making deposition thereon more difficult because of increased distance and because of the gentleness of slope on the wave- and current-cut rock floor.

Marine gravels may have at least two time relations. In one case the units are of original deposition and the coarser constituents were deposited with, or slightly antecedent to, the associated finer materials. In the other case the gravels were concentrated on the surface of the base level of deposition as the finer sediments associated with them in occasional deposition were carried seaward into deeper waters. Shells in these gravels are likely to be worn and corroded. The deposition of gravels in the latter relation represents a much longer interval of time than in the former in that they are concentrated from a considerable volume of sediments. A modified form of the second relation is that taking place where the bottom is arched upward locally, where sea-level falls, or where some other condition brings a part of the bottom into a position where it becomes subject to erosion and the coarser constituents of a considerable thickness of sediments are concentrated on that part of the bottom eroded. In each form of the second relation the gravels are a *part of the formation beneath the surface of the base level of deposition and not a part of the sediments that may be deposited thereon.* The succeeding deposit may

begin with gravels so that the stratigraphic break lies within the gravel deposits.

In the gravels thus concentrated, the interstices among the particles may become filled with finer materials when other sediments are deposited upon them. The materials filling the interstices are a part of the formation above the unconformity separating the gravels, and thus the unit beneath the unconformity contains materials of two time relations of which materials of organic remains may be a part, the more or less worn and corroded shells of the larger macro-organisms probably belonging to the underlying formation and the smaller macro-organic remains, and the tests of micro-organisms belonging to the overlying formation. This infiltration of fine materials into gravels previously deposited is what Galliher has termed interstitial sedimentation.[4] *The occurrence of the worn shells may lead to the conclusion that they were eroded from underlying strata and included in the gravels of which they are now a part, and thus lead to location of the unconformity beneath the lower gravels.*

Erosive and transporting powers of waves and currents.—Waves and currents depend for their magnitude on the one hand on the winds, tides, and other agents that set water in motion and on the other upon the extents and depths of the water bodies. Strong and long persisting winds for the same sets of conditions produce larger waves and stronger outgoing and shore currents than weak winds of short duration. Tides and tidal and wind currents vary in intensity depending upon the configuration of the shore (offshore islands included), the extent of the water bodies, and the depths of the water placed in motion. Bodies of water of great shallowness, such, for instance, as that of the Ordovician in which were deposited the mudcracked limestone exposed near Bellefonte, Pennsylvania, could not have had strong waves and currents, neither could there have been strong waves and currents over those areas of the Franconia sea of Wisconsin on which silts dried and developed shrinkage cracks over many hundreds of square miles.

Strong and large waves require for their development waters of great extent and considerable depth, and to give persistence to large waves and strong currents large bodies of water must be placed in motion. If the waters are very shallow for long distances from the shore it is impossible for strong waves to reach the shore; consequently, little erosion is accomplished thereon, gravels can hardly be produced no matter what the rocks of the shore, sands are possible

[4] E. W. Galliher, "Geology of Glauconite," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 19 (1935), p. 1597.

but not probable, and silts, clays, and carbonates are the only things likely to attain deposition. However, if deep waters obtain beyond a narrow shallow-water belt, large waves can develop and reach the shore with sufficient power to erode. Such waves mean gravel on shores composed of rock that can produce gravel and strong shore or outgoing currents depending upon the configuration of the shore. Fairly deep water *is essential to develop waves and currents capable of acquiring gravels from shores, very shallow water means impotent waves and little or no gravels.*

Competency and capacity of currents vary with velocities, shapes and specific gravities of particles, the nature of the surface over which transportation takes place, and the association of the various sediments. Particles naturally move most readily at high velocities of currents. Little competency is required to move spherical and ellipsoidal particles and, as shown by Landon, particles of these shapes tend to be separated from those of other shapes and to move outward from the shore.[5] A smooth surface of sand, hard silt, or an even rock floor, facilitates movements as such makes rolling easy. If smaller particles are traveling in company with larger ones and the differences in dimension are of considerable magnitude, the larger ones may move more rapidly than the smaller as they present a larger surface against which currents may be directed. The work of Suchier[6] has shown that gravels of the diameter of a pigeon's egg may be moved over a stream bed covered with fine sediment by a current with velocity of 1.125 meters per second, and particles of the size of a bean at 0.897 of a meter per second. Gilbert[7] states that a velocity of 0.65 of a meter per second will move gravel of 4.9 mm. in diameter.

Submarine currents at numerous places on the ocean bottom are known to have velocities comparable to those already given, and over many large areas of the sea bottom they are known to be strong enough to keep the bottom free of sediment. There are areas in the English Channel, about the Mingan Islands in the Gulf of St. Lawrence, in the Strait of Belle Isle, in Florida Strait, in the Strait of Gibralter, south of the Azores, about the Canary Islands, in the Faroe-Shetland Channel, over the Wyville-Thompson Ridge, and in many other places that have currents strong enough to prevent deposition of all fine sediments which may be brought to those bottoms.

[5] R. E. Landon, "An Analysis of Beach and Pebble Abrasion," *Jour. Geol.*, Vol. 38 (1930), pp. 437–46.

[6] Suchier, "Die Bewegung der Geschiebe des Oberrhein," *Deutsche Bauzeitung*, No. 56 (1883), p. 381.

[7] G. K. Gilbert, *U. S. Geol. Survey Prof. Paper 86* (1914), p. 71.

In the Strait of Gibralter velocities have been measured as follows: 10 meters depth—1.18 meters per second; 46 meters depth—0.80 of a meter per second; 91 meters depth—0.85 of a meter per second; 274 meters depth—2.27 meters per second. Greater velocities seem probable since at the depth of 366 meters the movement of the water was so rapid that the sounding apparatus was wrecked by striking against objects on the bottom.[8] These velocities could move large particles with great ease and if gravels were possible of acquirement they would build gravel deposits over and leeward to the places of such velocities. Agassiz has stated that in the Strait of Florida the bottom velocities are those of a river, about 1.5 meters per second, and are such as to keep the bottom free of sediment. Heim[9] states that in the region of the Philippines on the submarine ridge between Sulu and Obi Islands, the Siboga Expedition found hard bottom at 680, 1476, 1504, and 2001 meters, showing that strong currents go down to those great depths. It should be noted that many of these bottoms are in bathyal depths, one being even in the abyss, and that the figures of velocity give competencies adequate to transport gravels.

Characters of adjacent lands.—The characters of the adjacent lands constitute a second factor bearing on the deposition of clastics in the marine environment. The most important characters—disregarding those where certain geological conditions, as glacial phenomena, present or past, exist, and render possible a supply of prepared particles—are those of elevation, climate and character of rock.

Elevation makes possible ready removal of the weathered products and thus maintains a rock surface from which additional clastics may be dislodged. High lands generally yield large volumes of clastics, but if these high areas are considerable distances from the sea, the long transportation reduces the dimensions of the particles so greatly that they rarely reach the sea other than as clay, silt, and sand. High lands a short distance from the sea may make contributions. Low lands yield little else than clays, silts, sands, and colloidal and dissolved materials. Active diastrophism progressively renews the elevatory conditions and thus favors continued formation of clastics.

Climate has influence in determining exposure, maturity of decomposition, thickness of soil cover, development of vegetable protection, and effectiveness of precipitation and transport. The best climatic conditions—those connected with glaciers not considered—from the point of view of providing an ample volume of clastics, are those that

[8] J. Murray and J. Hjort, *Depths of the Ocean* (1912), pp. 285–87.

[9] A. Heim, "Über submarine Denudation und chemische Sedimente," *Geol. Rundschau*, Vol. 15 (1924), p. 2.

produce a poorly effective vegetable cover, and thus a limitation of mature decomposition and a concentrated and seasonal precipitation so that the unprotected surfaces can be vigorously attacked over short periods of time with high competency and great erosive power to the runoff. Additional phenomena giving a somewhat like result are fire, close grazing and human activities. Fire makes possible an increase in the supply of clastics as the vegetable protection is thereby destroyed and the underlying rock made vulnerable to attack and removal. Close grazing may bring about the same result. Man's intensive agriculture has not only involved removal of the protecting vegetation but his stirring and loosening the soil cover has hastened its removal with rock exposure as a sequel.

The character of the rock is important as some rocks yield no or only a small volume of clastics.

It is worthy of note, however, that most of the coarse clastics developed on the land remain there until reduced to particles of small dimension, when they are removed as clay, silt, or sand. These coarse clastics thus have little influence on the deposition of marine gravels. Only if the gravels are produced a few miles from the sea may they be expected to be ultimately deposited under marine conditions.

Character of the shores.—The shore is the chief source of the constituents of marine gravels and the two important facts thereon, so far as the shore is related to the production of marine gravels, are those of the character of the composing rocks, and the height and configuration of the shore.

Coarse clastics can not be supplied if the rocks from which they must be derived are of such character as not to produce gravel.[10] The ability of coastal rocks to supply gravel depends upon their composition, texture, and structure. Clay, sand, and chalk shores can supply essentially nothing, the first two exemplified by the clay and sand cliffs along considerable extents of the north coast of the Gulf of St. Lawrence in the vicinity of Harbour St. Pierre, Mingan, Long Point, et cetera, and the last by the chalk cliffs of England and France, the only large particles in the latter being derived from flint concretions therein. Shores composed of such sandstones as those forming the Cambrian of the upper Mississippi Valley would yield essentially no gravel. On the other hand, shores composed of closely and much jointed quartzite, limestone, or other firm rock may produce a large volume of coarse clastics. Some of the limestone cliffs of Anticosti Island, rising fully 200 feet vertically from the wave- and current-cut

[10] J. Barrell, "Marine and Terrestrial Conglomerates," *Bull. Geol. Soc. America*, Vol. 36 (1925), pp. 286–91.

rock floor, yield tremendous volumes of clastics, mostly dumped by undermining directly into the sea and this material does not tarry long at the bases of the cliffs. On the other hand, shores composed of little jointed resistant rock yield slowly and if the cliffs are not high the yield of coarse clastics from shores composed of such rocks may be almost nothing.

High shores, other conditions being equal, yield more clastic material than low in that the erosion about the water's edge undermines the top part of the cliff, causing it to topple over and fall into the water or upon the beach, thus yielding a greater or less quantity of broken rock for removal by the waves and currents, whereas on low shores the acquirement must be made almost wholly by direct abrasion with the probability that most of this will be relatively fine in character.

Possible thickness and extent of marine gravels.—How thick is it possible for gravels to accumulate in the marine environment? Barrell[11] expressed the opinion that the possible thickness of marine gravels in the littoral and neritic environments, except under particular and special conditions, would be considerably less than 100 feet, a view somewhat modified in a posthumous paper published in 1925. He generalized "that marine gravels are not carried beyond depths of 20 or 30 fathoms, nor horizontally to distances of more than 10, or perhaps in a few extreme cases, 15 miles, from shore." Occurrences of gravels at greater depths and distances from the shore he accounted for as due to former lower levels of the sea.

Barrell's generalization may be generally accepted with respect to distance from shore, but limiting the depth to 20 or 30 fathoms seems too small as there are numerous places where such depths are much less than a half mile from shore. The thickness of gravels, provided the supply is ample, depends on the depth of water in which deposition takes place, the slope of the bottom, distances of the sites of deposition from the sources, velocities of currents, and what sea-level is doing. All of these factors were theoretically considered by Barrell, but he does not seem to have been personally familiar with the extents of current velocities in the depths or the closeness of some deep bottoms to the shores. It has been shown that there are numerous places in the depths where current velocities are adequate to give the competencies capable of transporting gravels and it is known that many deep bottoms are quite close to the shore. There conditions would readily carry gravels to the depths.

[11] J. Barrell, *Bull. Geol. Soc. America*, Vol. 20 (1909), p. 620; Vol. 36 (1925), pp. 304–12.

If deposition takes place at depths of 200 meters, a depth that not uncommonly exists very close to shore, and thus with steep slope to that depth, and if sea-level is stationary and supply ample, the possible thickness is equal to 200 meters minus the distance from sea-level to the base level of deposition, but it must be remembered that after the bottom at the place concerned has been built to the base level of deposition, gravels may move over that surface to waters deeper than 200 meters and the thickness will increase seaward because of movement to deeper waters. The result would be a *wedge-shaped unit, and not a sheet of clastics, with limited width perpendicular to the shore and a greater or less linear distribution, as determined by the conditions, parallel with the shore.*

Under conditions of rising sea-level with respect to the bottom the possible thickness may exceed that under conditions of stationary sea-level with the gravels rising stratigraphically in the section as the various lithologies move landward as the shores retreat. *The textural phases would thus transect the time units and would be inclined seaward at a steeper angle than the latter.*

It is not to be assumed that every bedding unit would be gravel but that gravel units would be interbedded with carbonates or clastics of smaller dimensions, just as in the Anticosti section layers of gravel are interbedded through 2,400 feet of limestone and shales, with the gravels in the minority. The shore in this case could not possibly have been nearer than 30 miles, and everything indicates that the waters of deposition were shallow. Elias[12] has called the writer's attention to interbedded marine Triassic conglomerates and sandstones in the vicinity of Vladivostock, Siberia. These in one exposure are over 200 feet thick and have interbedded sandstones toward the top. In another section the interbedded conglomerates and sandstones attain a thickness of 900 feet. They extend over an area that is about 45 miles north and south and about 35 miles east and west. These occurrences prove that it is readily possible for marine conglomerates to attain thicknesses greater than postulated by Barrell.

As already noted, a gravel unit grades seaward into finer clastics and is of wedge-like form interbedded in sediments of finer character. Marine gravel deposits of notable thickness could rarely or never be of blanket character and in most and perhaps all instances would be wedges or lenses of limited extent perpendicular to shores but with greater extent parallel thereto.

[12] M. K. Elias, personal communication, letter of March 27, 1936. These Siberian conglomerates are interpreted by Elias as having been deposited along a shore bordering an ancient Triassic massive ridge.

CONDITIONS THAT CONTROL DURING THE DEVELOPMENT OF A SURFACE DESTINED TO BECOME AN UNCONFORMITY BENEATH MARINE DEPOSITS

The term unconformity is defined as the surface separating two distinct deposits, this surface representing a time during which no deposition took place over the area where the unconformity exists, or, if deposition did take place, the deposits were removed before the deposition of the strata above the unconformity. There must always be places over the sites of deposition of the time represented by an unconformity where no unconformity develops because deposition never ceases since erosion certainly continues on the existing land areas and erosion would compel deposition. The failure of deposition over the area of an unconformity may be due to several causes. The area may have been land before it was submerged by the sea and thus subject to erosion for a longer or shorter period of time. As a land area, it would have been likely to have been covered by a greater or less thickness of residual soil which under ordinary conditions would have been planed away by an invading sea together with some of the underlying rock. There would thus be a stratigraphic break between the strata below the unconformity and those above. Deposits succeeding the unconformity would begin with those of shallow water, might either continue as such, or pass into those of deeper water depending on sea-level. The immediately succeeding deposits could not very well be those of deep water.

On the other hand the surface destined to become an unconformity may develop when the sea bottom has been built to the base level of deposition with non-deposition following, or when the bottom has been raised or warped above the base level of deposition, with erosion to that level as a sequel. In several excellent papers Heim[13] has called attention to the absolute certainty of submarine erosion or no deposition over extensive areas of the existing ocean bottoms and has found unconformities in the Alpine region which he considers can not be interpreted as other than of submarine development and not one of these is accompanied by a true basal conglomerate or any sign of a transgression of the sea over a land area. As a general proposition he states that on some bottoms of the sea, times of deposition (p. 373, 1934) alternate with times of non-deposition or even submarine erosion without elevation of the sea bottom above the water, and if a

[13] A. Heim, "Über submarine Denudation und chemische Sedimente," *Geol. Rundschau*, Vol. 15 (1924), pp. 1–47; "Stratigraphische Kondensation," *Eclogæ geologicæ Helvetiæ*, Vol. 27 (1934), pp. 371–83; —— and O. Seitz, "Die Mittlere Kreide in den Helvetischen Alpen von Rheintal und Vorarlberg und das Problem der Kondensation, Denkschriften d. Schweiz.," *Naturf. Gesell.*, Vol. 69, Mem. 2 (1934), pp. 273–83.

regional disconformity exists between concordant marine sediments, that the discontinuity developed either through submarine erosion, or "omission" succeeded by "recession" of deposition. If the beds above this disconformity are of deep water (bathyal) nature and the underlying beds are of thin-bedded units which can be followed over extensive areas, the submarine development of the hiatus can not be doubted.

An unconformity of this origin should show an even concordance of the contacting bodies, a probable absence of clastics, and the presence of products of submarine production. The phenomenon has also been emphasized by Andree.[14]

Oceanic research has shown that there is extensive circulation in the deep bottom waters of the ocean far from land where the sediments naturally are extremely fine clastics or carbonates. This circulation is known to be adequate in places to dissolve carbonates precipitated in the surface waters or developed on the bottom, and thus partially or completely to prevent their deposition; this circulation also is competent to transport partially or completely to other places on the bottom any fine clastics or insoluble residues derived from the dissolved carbonates. The net result is no or limited deposition and either the development of a discontinuity in great depths far from land or a great decrease in the thickness of the sediments deposited. A return of deposition conditions or a "recession," using the term of Heim, will bury the surface on which there has been no deposition and produce the unconformity. It will be noted that two types of submarine discontinuity are indicated. In the one, deposition stops either because the bottom is built to a position beyond which it can not rise or because conditions have entered to prevent deposition, the surface of the bottom in each case being in a condition of equilibrium or at the position of the base level of deposition. In the other type the bottom has been raised by diastrophism to a level which renders it subject to erosion and thus leads to removal of some material.

The time interval represented by an unconformity developed on land is relatively long; that represented by an unconformity developed beneath the sea because the bottom has been built to the base level of deposition or warped above that level and subsequently eroded thereto, may be short or long. In the former case, the overlying materials rest upon a surface first eroded on land and later modified by waves and currents, and these materials may range from chemical

[14] K. Andree, "Über stetige und unterbrochene Meeressedimentation, ihre Ursachen, sowie Bedeutung für die Stratigraphie," *Neues Jahrb.*, etc., Beil. Bd., Vol. 25 (1908), pp. 366–421. (This work and those by Heim should be read by every sedimentationist and stratigrapher.)

(chemical-organic) precipitates through muds, silts and sands to gravels, depending upon the sources of supply, which in turn depend upon the lithological characters of the materials of the coast, the depths of water adjacent to the coast, the character of the surface and the climate inland, and the existence of streams with sufficient competency to carry clastic materials to the sea.

UNCONFORMITIES BENEATH MARINE DEPOSITS

On the Strait of Belle Isle the Lower Cambrian rests on the deeply eroded pre-Cambrian, and there seems to be little doubt that the surface on which the Lower Cambrian rests received its last erosive action from the work of waves and currents. The deposits immediately above the unconformity consist almost entirely of coarse and fine clastics derived from the pre-Cambrian. The clastics range in thickness to a maximum of 285 feet, and the deposition seems to have been made over a surface developed on land and submerged under conditions of rising sea-level.

On the Mingan Islands in the northern part of the Gulf of St. Lawrence the Mingan formation (Chazy) rests with unconformable relationships on the eroded surface of the Romaine formation (Beekmantown). The unconformity is angular and it is immediately overlain by one or more feet of quartz pebble conglomerate followed by sandstone and shale, or by sandstone and shale without the conglomerate. The deposition unquestionably took place over a surface developed on land, and which was modified as it became submerged under conditions of a rising sea-level. The underlying Romaine formation rests unconformably on the pre-Cambrian complex, and if coarse materials are present, the thickness must be slight, as there is simply not space for a great thickness between the basal exposed strata of the Romaine formation and the nearest exposed rock of the pre-Cambrian. Nevertheless the rocks of the pre-Cambrian are excellently qualified to supply large quantities of clastics. This unconformity developed in the same way as that between the Romaine and Mingan formations.

At Montmorency Falls near the city of Quebec, Canada, the Trenton limestone rests with unconformable relationships on the pre-Cambrian gneiss with which it is in direct contact without intervening clastics, although the gneiss is of a character to afford such. The surface of the unconformity certainly developed on land and was later modified by wave and current action as it became submerged.

At Louisville, Kentucky, Middle Devonian limestones rest on Middle Silurian limestones with no separating clastics, the two lime-

stone units having such conformable relationships as to suggest a succession of continuous depositions, which, of course, the fossils contained in the two limestones show to have been impossible. It is possible that the separating surface developed beneath the sea but it is generally considered to be a land surface modified by submerging waters.

Unconformities that developed beneath the sea have had little or no recognition in North America and the development of most of them has been explained by land intervals. However, there must be many stratigraphic breaks in the geologic column of North America that developed beneath the sea, particularly in those parts of the column that were deposited when the land areas were low and the epi-continental seas shallow since during such times the bottoms of the sea over extensive areas would certainly have been built to the profile of equilibrium, or cut to the base level of deposition, and no deposits would have been made over such areas until sea-level rose or there was an increase in the supply of sediments. Unconformities of such development should be expected in North America east of the Rocky Mountains in strata of the late Cambrian, Ordovician, Silurian, Lower and Middle Devonian, Mississippian, Pennsylvanian, Cretaceous, and Tertiary.

An unconformity that is seemingly best explained as due to submarine development is that said to be present in the upper Mississippi Valley in the lead and zinc district between the Ordovician Decorah formation and the overlying Galena. The contact is characterized by the presence of phosphatic nodules and by a decided break in lithology. It is possible that the contact between the Franconia formation and the overlying Trempealeau formation of the Upper Cambrian of the upper Mississippi Valley may be of submarine development. The strata of the Upper Franconia exhibit little evidence of erosion, and the strata seem completely concordant. A conglomerate marks the contact, but it is composed of more or less elongated disk-shaped particles of very weak and poorly indurated glauconitic sandstones and fine-grained yellow sandstones—rocks too weak to have resisted serious wave action, which certainly would have existed if a land area had been submerged.

Unconformities of submarine development have received greater recognition and appreciation in Europe, and in this work Arnold Heim[15] may be considered to have been a leader in emphasizing their

[15] A. Heim, "Über submarine Denudation and chemische Sedimente," *Geol. Rundschau*, Vol. 15 (1924), pp. 8–20. See also K. Andree, Über stetige und unterbrochene Meeressedimentation, etc. (1908), and *Geologie des Meeresbodens*, Bd. 2 (Leipzig, 1920).

importance. Two unconformities, identified by Heim as of submarine origin, are present over extensive areas in the Helvetian Swiss Alps in the Dogger and Malm. The Bajocian at the base is represented by the Echinodermenkalk. The Bathonian is either wanting or is represented by a fossiliferous bed often only a decimeter thick. The Callovian follows, with a range in thickness from a decimeter to a meter, and consists of a ferruginous oölitic limestone known as the Eisenoölithkalk. This is locally rich in ammonites. The Oxfordian is usually not present and overlying the Eisenoölithkalk is the Argovian (Schiltkalk). All of these strata are stated to be in complete concordance, but to contain two decided discontinuities, one above, the other below, the Eisenoölithkalk. Heim states that emergence is unthinkable, as otherwise the thin fossil-bearing bed of the Callovian could not have existed over extensive areas and the Argovian Schiltkalk could not have rested without a trace of littoral material upon the Eisenoölithkalk.

Also in the Helvetian Alps Heim states that the Dogger of the Jurassic lies concordantly on the Triassic and that a marine unconformity is to be suspected. In the same region the Upper Cretaceous Senonian (Wangschichten) contacts with sharp boundary upon the Upper Cretaceous Campanian (Leistmergel) without a trace of emersion phenomena. The Leistmergel is stated to be of deep water origin, and, locally, possesses sediments that are transitional to the overlying strata.

In the South Alps of Switzerland the Lower Cretaceous rests with sharp contact on the Upper Malm, there 40 meters thick. There are no Lower Malm and Upper Dogger, and the Upper Malm is underlain by a 1,000-foot section consisting of the Middle Lias to the Dogger. Heim considers this contact with the Upper Dogger and Lower Malm to mark an outstanding example of submarine discontinuity of deposition followed by recession (pp. 13–14). The Lower Cretaceous is 50–100 meters thick and is overlain with sharp discontinuity by the Upper Cretaceous with total absence of the Middle Cretaceous. In each of these discontinuities concordant strata bound the contacts, and all are said to be of deep water origin, to lack any traces of emersion, and to exhibit sharp lithic changes at the discontinuities. All the evidence is said to indicate that from the Lias to the Upper Cretaceous there was a continuous body of deep water over the region with one discontinuity representing the Upper Dogger and the Lower Malm with recession during the Upper Malm, and another discontinuity representing the Middle Cretaceous with recession in the Upper Cretaceous. Heim gives other examples.

CRITERIA FOR DETERMINATION OF SUBMARINE UNCONFORMITY

If the surface of an unconformity is of land origin little difficulty is ordinarily experienced in its determination, and no attention is here given to criteria by which such unconformities may be identified. The criteria that follow apply to unconformities of submarine development. It is not proposed to enter into the problem in great detail, but to discuss some of the more important means of identification.

Phosphatic and manganese nodules.—These substances seem to be products determined by slow deposition and not necessarily related to an unconformity. If they are of authigenic and not of allothogenic origin, an unconformity should be suspected and at any rate the containing strata should probably be considered as representative of much thicker equivalents elsewhere. The nodules may be allothogenic in the sense that they were released on subaerial weathering from strata in which they were more or less widely scattered, and if such is the case they can have no bearing on the occurrence of a submarine unconformity. On the other hand they may be pene-authigenic in that they developed in the sediments of the bottoms and when subsequent conditions lowered the base level of deposition the finer materials were removed and the nodules concentrated. Again, they may be of strictly authigenic deposition with other sediments developed in association moved concomitantly on formation leaving the nodules. A submarine discontinuity exists in the two last cases. The volume or quantity of the nodules may be considered a measure of the slowness of deposition and thus the vertical extent of the discontinuity. The cart should never be placed before the horse, however, and the phosphatic nodules used as proof of the discontinuity as these may be developed without cessation of deposition, although the deposition may have been slow.

Glauconite.—This also seems to be a product of slow deposition irrespective of whether it developed according to methods of origin previously more or less accepted, or whether it was formed from the decomposition of biotite, as recently postulated by Galliher.[16] The presence of the mineral thus suggests[17] but does not prove a submarine unconformity for thick sections are known that contain glauconite throughout.

Changes in lithology and texture.—Changes in lithology may be expected as common occurrences in any neritic deposit. The numer-

[16] E. W. Galliher, "Glauconite Genesis," *Bull. Geol. Soc. America*, Vol. 46 (1935), pp. 1351–66.

[17] M. S. Goldman, "Lithologic Subsurface Correlation in the 'Bend Series' of North-Central Texas," *U. S. Geol. Survey Prof. Paper 129-A* (1921).

ous changes in competencies of the outgoing currents from day to day and from season to season, and the excessive competencies of the occasional storm may sweep clastic deposits of any texture from time to time over any other kind of deposit. One must first prove the unconformity before permission can be granted to use lithology and texture as evidence of its presence. The statements of some geologists that an unconformity may be determined by small changes in texture can hardly be taken at face value.

Unconformities developed beneath the sea may exhibit no apparent differences in the sediments above and below the unconformity and this criterion has thus no application. On the other hand the greatest changes of texture in a section may have no relation whatever to an unconformity.

Surface of erosion.—This is a positive characteristic, but it must be ascertained that the surface of erosion does not represent the effects of occasional deep cutting by waves and currents and is hence of little importance. No estimate of the thickness of the strata missing can be assumed from any relief of an unconformity.

Concordance of strata.—Concordance of strata, of course, obtains in any sequence of continuous deposition. If the summation of other characters proves an unconformity, its submarine origin may be considered established in the occurrence of a thin persistent unit beneath the unconformity at the top of the underlying sequence and by the presence, at the base of the overlying sequence, of sediments of deep-water origin.

Fossils.—Changes in fauna and flora indicate changes in environment. The factors that may produce these changes are very numerous and there are many among them that may produce pronounced floral and faunal changes. The differences in the flora and fauna, generally the latter, as plants have little value in marine deposits, must be of a magnitude beyond doubt. Mere differences in species do not suffice, or even differences in genera, since one may find these differences at present on different parts of the same sea bottom not very far removed from each other.

In general, there should be given up the somewhat common practice of assuming an unconformity every time there is a change in fauna, lithology, or texture, or when minerals favored by slow deposition as phosphate, manganese oxide, and glauconite are present.

FACTORS DETERMINING THICKNESS OF DEPOSITS

As shown on foregoing pages an unconformity represents a rate of deposition that is zero, or, if something is removed, a rate that is less

than zero. From these rates the magnitudes of the rates of deposition may rise to considerable figures with the upper limits not yet determined.

In considering thickness of deposits there are several factors that must be taken into consideration, and the two viewed as most important are the rate of supply and the position of the site of deposition with respect to the base level of deposition or erosion. Supply is related to the regions or the shores furnishing the sediments—the quantity available there—and upon the agents of transportation capable of carrying the sediments to the sites of deposition. It is obvious that where a sea borders a land which has little relief, is cloaked with an effective cover of vegetation, and has a shore guarded by a wide expanse of very shallow water, the quantity of clastic sediments supplied to the sites of deposition in the adjacent sea would be almost zero and certainly the rate of accumulation of clastic sediments would approach zero as a limit. If such bottoms were not favorable for organisms or for processes leading to the precipitation of carbonates or other chemical sediments, the deposits would be indeed scant. These deposits would be intensively screened for food by scavenger, microscopic, and mud-dwelling organisms, and a given thickness might have made many passages through the intestinal tracts of these organisms before final burial. If such conditions obtained for thousands of years, it might well be that many thousands of years would be represented by an inch or less of sediment. *There can be no thickness of clastic sediments if no clastic material is brought, and there can be no deposition of carbonate sediments if the conditions are not such as favor carbonate deposition.* On the other hand, a land of considerable relief, with such seasonal rainfall as to support an indifferent cover of vegetation, and with strong flood waters following and during times of rainfall, would yield large volumes of fine clastic sediments to give a rapid rate of deposition if distributed over a small area. A rapid rate of erosion over a large area, drained by a single large stream, would be attended by a more rapid rate of deposition over a more limited area.[18]

Over all sites of deposition there is some level for the conditions above which deposition can not continue. When this level has been attained permanent deposition is brought to a close until such time as the changed conditions bring about a new level which may be above the one previously made or below it. In the former case this makes

[18] Russell and Howe, *Geog. Rev.*, Vol. 25 (1935), p. 450, state that if the present rate of deposition of the Mississippi River "were extended back to the beginning of the Comanchean, the accumulated sediment would amount to a solid large enough to cover the entire state of Louisiana to a depth of 121 miles." The deposits of the Mississippi are spread over an area larger than the state of Louisiana but one that is smaller than the area of derivation.

possible additional deposition, and in the latter it compels some erosion. This level is the base level of deposition or erosion depending on which process is operating. This level is extremely sensitive to changes in conditions,[19] and any changes in the regions of supply or over the sites of deposition, whether these changes are climatic, topographic, orogenic, organic, sedimentary, et cetera, may raise or lower the level, thus either permitting additional deposition or compelling erosion. On an alluvial fan, flood plain, delta, sea bottom, or other site of aqueous deposition, this level is attained when these deposits are built to such level that the waters flowing over the surface have competency to carry away all sediments brought to these surfaces. When this condition of equilibrium is attained permanent deposition ceases.

In the sea the top of the wave- and current-cut rock floor developed adjacent to the shore represents a base level of marine erosion, and the surface of the wave-built terrace outward therefrom represents the base level of marine deposition. It is obvious that under conditions of a stationary sea-level these surfaces can receive no permanent deposits. Under conditions of a rising sea-level, the former may receive deposits on its seaward margin coördinate with the rise of sea-level and the latter over its entire surface. If sea-level rises rapidly and the supply of sediments is ample, the rate of deposition may approximate equality to the rise of sea-level, and if this is an inch in a hundred years, an inch in a thousand years, or an inch in ten thousand years, the rate of deposition proceeds at a corresponding or a slower rate. If the supply is not ample the rate will be slower than the rise of sea-level.

The result of slow rise of sea-level may thus concentrate in a small thickness the history of a long period of time, a time that may elsewhere be represented by hundreds and possibly thousands of feet of sediments. Thus in the Alps of eastern Switzerland Heim[20] has noted that in the vicinity of Allgau the lower and middle Albian of the Cretaceous has a thickness of 40 meters in the southwest but near Allgau almost the whole Albian is represented by a very fossiliferous phosphatic unit of half a meter thickness that has yielded thirty-five species and varieties of ammonites and farther toward the east the Albian consists of a phosphate bank with a thickness of 0.8 meter. In the northeast in the Vorarlberg district the Hauterivian horizon is 10 to 40 meters thick toward the north and 600 meters in the south-

[19] J. E. Eaton, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13 (1929), pp. 713–61.

[20] A. Heim, "Stratigraphische Kondensation," *Eclogæ geologicæ Helvetiæ*, Vol. 27 (1934), pp. 372–82 (378).

ern distribution.[21] Wanner[22] has shown that on the Island of Timor in the East Indies an ammonite-containing layer with a thickness of 2 meters represents all of Karnian and Norian time of the Jurassic and moreover contains 462 species of ammonites. Adkins[23] in his description of the Eagle Ford shales of the Upper Cretaceous of Texas has noted that in north-central Texas, the entire Eagle Ford formation is only 5 feet thick and consists of clay containing angular boulders of limestone up to 18 inches in length whereas near Austin, only a short distance away, the Eagle Ford has a thickness of 35 to 40 feet.

Such great decrease in thickness due to slowness of deposition has been termed "Kondensation" by Heim ("condensed deposits" of English writers) and the zone or formation thus condensed by reason of slowness of deposition a "kondensation layer." In it the fossils might be expected to be better preserved toward the base, but its slight thickness would have an association of fossils which elsewhere are distributed through a much greater thickness. In the greater thickness the faunas could be arranged in zones; in the condensation layer such zoning probably would not be possible. The number of species of fossils in the condensation layer might be expected to be large, as there might be concentrated therein all the species elsewhere distributed through a greater thickness. Heim states that condensation zones are unusually rich in fossils. The writer inclines to the view that the condition of slow deposition permits the scavengers to destroy the organic material and that the organic material remaining represents but a small fraction of those organisms that dwelt on the bottom during the deposition of the condensation layer. He agrees fully with Schuchert[24] that decreasing thickness of a unit is likely to be accompanied by a decrease in fossil content. Condensation layers usually seem to contain phosphatic nodules and glauconite.

Seaward of the wave- and current-cut rock floor and of that part of the bottom previously built to the base level of deposition there is bottom below the base level of deposition and here deposits may accumulate until each part of the bottom is built to that level. The thickness possible for a given unit of time is relatively small on the landward margin of the bottom as long as sea-level is rising slowly, but a greater thickness is possible seaward. Under conditions of a more

[21] A. Heim and O. Seitz, "Die Mittler Kreide in den Helvetishen Alpen," etc., Vol. 27 (1934), pp. 372–82 (378).

[22] J. Wanner, "Mesosoikum von Niederl. Indien," *Leid'sch. Geol. Mededeelingen*, Vol. 24 (1931), p. 572.

[23] W. S. Adkins, "The Mesozoic System in Texas," in "The Geology of Texas," Vol. 1, *Univ. Texas Bull. 3232* (1932), p. 435.

[24] C. Schuchert, *U. S. Nat. Res. Council Bull. 80* (1931), pp. 10–53.

rapid rise of sea-level, *a greater thickness is possible on the landward margin of the deposits in the same unit of time, but, if the supply remains the same, the thickness in the same unit of time over the deeper bottoms is less than in the first case over the same area since a part of the available quantity is deposited on the shoreward bottoms.*

It is thus obvious that at each place on the shallow sea bottoms there are two sets of conditions—stationary sea-level and rising sea-level—in each of which there is a rate of deposition for each condition with respect to sea-level and for each condition with respect to supply. This tends to make the rates of deposition for each particular type of clastic deposits almost infinite in number. *From this conclusion it follows that the various estimates of time based on the thickness of deposits are hardly worth the paper on which they are written.* The same may be said for the relative time values of one type of deposit compared with another, as, for instance, the statement that a given thickness of sandstones and shales in terms of the time of deposition represents about one-seventh the time required for the deposition of an equal thickness of limestone. In general, the rates of deposition for shales should be greater than for sandstones, and those for sandstones greater than the rates for limestones since the supply ratio of these three varieties of sediments as released from igneous rocks is 82:12:6, but as supply is only one of the two important variables concerned, it does not follow that the ratio of ultimate supply bears a particularly close relation to the rates of deposition over a given area. Schuchert has discussed this question in detail and on the basis of various assumptions has attained results that are interesting but can hardly be considered much more than intelligent guesses.

In the deep waters in the middle or lower parts of the bathyal or in the abyssal environment it might be assumed that the rates of deposition would approach uniformity but even in these environments there are variable factors that bring about variations in the rates of deposition and hence thickness of deposits. The materials deposited in these environments, speaking generally, are fine clastics or carbonates, the latter probably mostly of planktonic or nektonic origin. The fine clastic materials should not be expected to have any more uniform distribution than the currents to which their distribution is due and variations in the current competencies would lead to deposition in some places and none in others. Planktonic carbonate deposits would be likely to totally disappear if they were compelled to fall through carbon dioxide-rich cold waters on their way to the bottom, so that possibly only benthonic carbonate materials might attain permanent deposition and even these might be wanting. Elsewhere

these cold carbon dioxide-rich waters might be compelled to rise and be warmed, with resulting loss of carbon dioxide and consequent carbonate deposition. Thus at one place in deep waters there might be no deposits, elsewhere very thin deposits, and elsewhere maximum deposits, the deposits ranging from fine carbonates to fine clastics.

The conclusion to be derived from this discussion is that there has not been discovered as yet a method of obtaining time relations from thickness of deposits and that thickness and rates of deposition are determined by relations of the sites of deposition to base levels of deposition—relations almost if not infinite in number—and to relations of supply and means of transportation—again infinite in number. Thus, there are places that receive no deposits, and others that receive deposits through a range in thickness from a fraction of an inch to an unknown maximum.

SUMMARY

It has been shown that under conditions of a stationary sea-level there may be gravel deposits in the littoral zone and a bare wave- and current-cut surface seaward therefrom that is free of deposits, and beyond this surface there will be deposits of a degree of coarseness consonant with the conditions. After the bottom of the last area is built to the base level of deposition this area will be built outward into the sea and thus the deposits may attain thicknesses commensurate with the depth of waters into which they are built and may reach a great thickness if deep waters are close to the shore. The distribution seaward and the thickness of the deposits are functions of the supply and of the depths of the waters, the sediments *having wider distribution and lesser thickness the less deep the waters, and lesser distribution and greater thickness the deeper the waters*. As the competencies of the outgoing waters vary from place to place and from time to time it results that each deposit should be expected to pass laterally into some other of different texture or different lithology, and each bed at any place to pass upward into rock of different texture or lithology, *with the general result that the deposits increase in coarseness upward*. The textures may be expected to range from clays to gravels, and the lithology from clastics to carbonates.

Under conditions of a rising sea-level, the landward margin of the deposits migrates shoreward and at the same time rises stratigraphically, with lateral variations in texture and lithology and with variations to the same degree in the vertical section and a general tendency to *decrease in coarseness with progress upward in any section*. With periodic or intermittent rise of sea-level there is a combination of both results. At all times the thickness and extent of the clastic gravel de-

posits are directly related to the quantities supplied and to the relation of the sites of deposition to the base level of deposition.

Many marine gravel deposits (conglomerates) have no significance with respect to unconformities and many unconformities beneath marine deposits are not accompanied by gravels and under certain conditions the development of the surface destined to become an unconformity beneath marine deposits is such that gravel deposits are precluded. This is almost certain to be the case if the unconformity developed far from land under submarine conditions. Changes in texture of clastic deposits have little or no bearing on the presence or absence of an unconformity. Many unconformities are of submarine origin—the result of omission of deposition followed by recession.

The character of the surface of an unconformity and the coarseness of the sediments deposited upon it, if the ages of the enclosing rocks are unknown, give no basis for estimating the time involved. This estimate must be drawn from the fossils and the structural and other characters of the rocks above and below.

The thickness of strata deposited during any time interval and the rates of deposition depend largely upon the relations existing between the sites of deposition, the base level of deposition, and the regions of supply. These are variables which depend upon other variables so that there are infinite rates of deposition and hence a wide range for the thickness of deposit possible for any time unit. Other important factors concerned with rates of deposition are the currents over the sites of deposition and the carbon dioxide content of the waters.

It should be obvious to any reader that this paper is somewhat iconoclastic in tenor and it may lose effect for that reason, but the writer has little patience with the rather smug acceptance of ancient doctrines merely because they have behind them the voice of authority and the cloak of antiquity. As stated in the introduction, it is the privilege and also the responsibility of the geologist to examine old concepts and to accept them if they can stand the examination and modify or reject them if they can not. It is easy to accept ancient concepts without question as such is the path of least resistance, but it is not the path of progress nor the way of science.

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MOVEMENTS OF GROUND WATER[1]

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ABSTRACT

The movement of water through formations having capillary openings is generally laminar and obeys Darcy's law, at least down to very low gradients. About 1,000 samples tested in the Geological Survey laboratory have coefficients of permeability ranging from .001 to 90,000, indicating probable velocities ranging from a fraction of a foot to a few miles in a year. The Thiem field method gives promising results for determining permeability. Movement through subcapillary openings is important but poorly understood. Molecular attraction of the water offers great resistance to movement and compression.

Water in rocks tends to move from a position of high pressure to a position of low pressure, both along and across the strata. Pressure changes are transmitted with much lag under water-table conditions and less lag under artesian conditions, according to the transfer of water involved. With respect to development of cones of depression, oil wells somewhat resemble water-table wells. Essentially static conditions of water or oil may be found in underground reservoirs that are completely sealed or sealed at one end or that contain fluids that differ in specific gravity, as water and oil, or fresh and salt water.

INTRODUCTION

Some years ago the writer discovered that the ground-water hydrologists and a group of students of agriculture and soil were dealing with similar problems relating to the behavior of water in the earth's crust, but each group was content to study its own literature and use its own terminology without much concern as to the help that could be obtained from the other group. Since that time an effort has been made to establish contacts between the two groups, and this effort has had very wholesome results. A somewhat similar lack of contact has existed between the ground-water hydrologists and the geologists and technologists who deal with problems involving the physics of natural oil and gas.

Ground-water hydrology is an older science than the physics of natural oil and gas and doubtless rests on a broader foundation, but in recent years there has been intensive work in some lines of the physics of natural oil and gas that has gone far beyond the comparable work in hydrology. The study of oil and gas is like the study of ground water in being in the border land of the fields of geologists, physicists, and engineers; the geologists generally having the most comprehen-

[1] Presented at the meeting of The American Association of Petroleum Geologists in Dallas, Texas, March 23, 1934. Manuscript received, January 27, 1936.

[2] Geologist in charge, Division of Ground Water, United States Geological Survey. Published with the permission of the director of the Geological Survey.

sive understanding of the problems but being to some extent amateurs in the rigorous application of the principles of physics to these problems. The great group of geologists who in the last 25 years have gone into oil work would have been better equipped for their work if the departments of geology in the universities in which they were educated had given the same serious attention to hydrology that they gave to paleontology, petrology, and mineralogy. In the future training of geologists, more attention should be given to the mechanics of natural fluids—that is, to the geophysics of water, oil, and gas.

LAW OF MOVEMENT THROUGH CAPILLARY OPENINGS

The fundamental law of the movement of water through formations having small openings is extremely simple; namely, that in any given stratum the rate of flow varies directly as the hydraulic gradient. This law was announced in 1856 by the French hydraulic engineer, Darcy,[3] but the basic principle was established earlier by Poiseuille.[4] A great amount of more recent work by many investigators has tended to support the essential accuracy of this law. Tests of permeability of about 1,000 water-bearing materials have been made in the hydrologic laboratory of the United States Geological Survey. Almost every one of these tests has been made with several different hydraulic gradients and hence has to some extent constituted a demonstration of Darcy's law.

Some hydrologists have held, however, that under very low gradients, such as occur in some places in nature, the rate of flow may become disproportionately small or the flow may cease altogether. Because of the great practical importance of this question, we undertook to investigate the law of flow under very low gradients. The first tests were made by Norah Dowell Stearns[5] and the writer in 1923 by means of a simple apparatus of the discharging type, shown in Figure 1. The principal test was made on a sample of clean, fine to medium sand from Fort Caswell, North Carolina. About 37 per cent of this sand is between 0.5 and 0.25 millimeter in diameter, about 56 per cent between 0.25 and 0.125 millimeter, and only about 2.4 per

[3] H. P. G. Darcy, *Les fontaines publiques de la ville de Dijon, Paris, 1856*. See C. S. Slichter, "The Motions of Underground Waters," *U. S. Geol. Survey Water-Supply Paper 67* (1902), pp. 18, 19. See also bibliography in C. S. Slichter, "Theoretical Investigations of the Motion of Ground Waters," *U. S. Geol. Survey Nineteenth Ann. Rept.*, Pt. 2 (1899), pp. 380–84.

[4] J. Poiseuille, "Recherches Experimentales sur le Mouvement des Liquides dans les Tubes de tres petit Diametre," *Mem. savants etrang*, Vol. 9 (1846), p. 433.

[5] N. D. Stearns, "Laboratory Tests on Physical Properties of Water-Bearing Materials," *U. S. Geol. Survey Water-Supply Paper 596* (1927), pp. 144–63.

cent of smaller grain. The effective size is 0.14 millimeter and the uniformity coefficient is 1.9. The results showed that Darcy's law holds in the sand that was tested at least down to a gradient of 5 feet

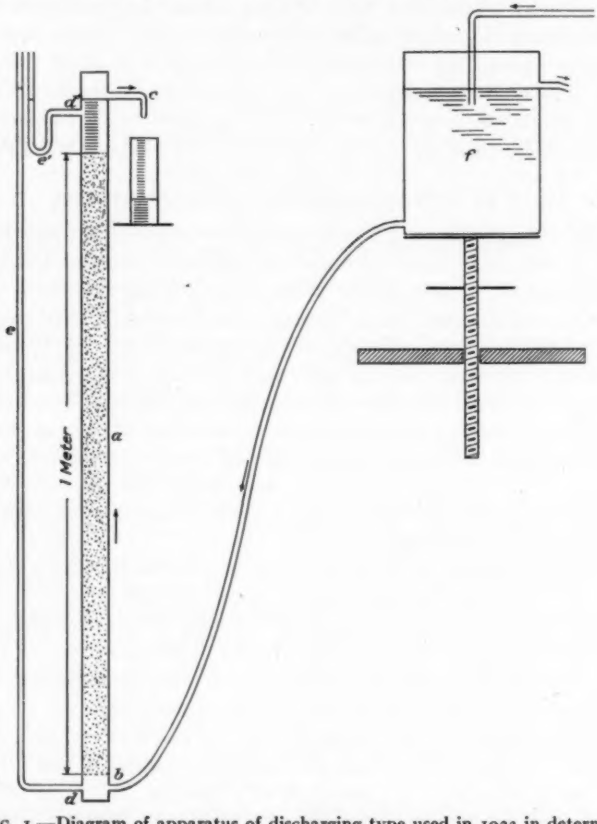

FIG. 1.—Diagram of apparatus of discharging type used in 1923 in determining permeability under low hydraulic gradients. *a*, percolation tube; *b*, intake; *c*, discharge; *d*, *d'*, openings into the pressure gages *e* and *e'*; *f*, supply reservoir.

to the mile. In 1933 V. C. Fishel and the writer constructed an apparatus of the non-discharging U-tube type in which the temperature is kept constant and evaporation is prevented (Fig. 2).[6] Tests made with this apparatus up to the spring of 1934 showed that in the sand that was tested Darcy's law holds down to gradients considerably less

[6] O. E. Meinzer and V. C. Fishel, "Tests of Permeability with Low Hydraulic Gradients," *Amer. Geophysical Union Trans. 1934*, Pt. 2 (1934), pp. 405–09.

than 5 feet to the mile—apparently to gradients less than 1 foot to the mile. More recently Fishel[7] made further tests with essentially the same apparatus and obtained results consistent with Darcy's law, within the range of probable error, for gradients of less than 1 inch to the mile. He concluded that these tests show that for the material tested, the rate of flow varies directly as the hydraulic gradient, down to a gradient of 2 or 3 inches to the mile, and that there are indications that Darcy's law holds for indefinitely low gradients. The

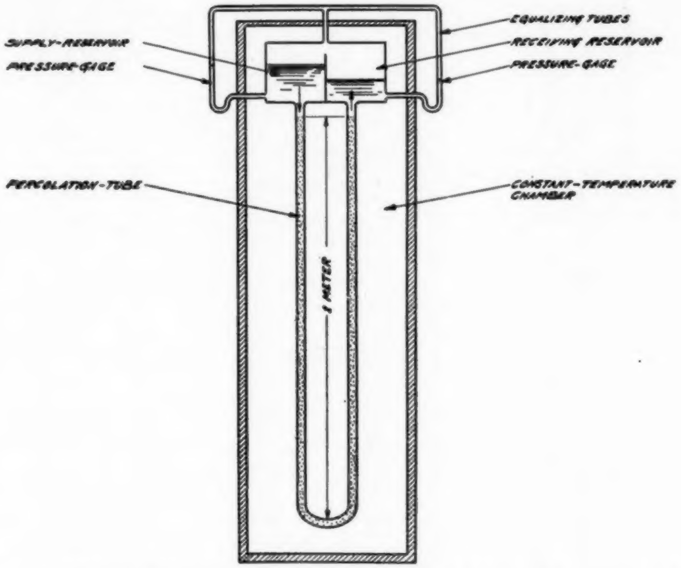

FIG. 2.—Diagram of apparatus of non-discharging U-tube type used in 1933–1935 in determining permeability under low hydraulic gradients.

results of his test No. 11 are shown in Figure 3. The same results are presented in Figure 4, in which the observed data are shown in relation to a theoretically computed curve.

The coefficient of permeability used in the hydrologic work of the Geological Survey is expressed by the rate of flow of water, in gallons a day, through a cross section of 1 square foot, under a hydraulic gradient of 100 per cent, and at 60°F. This coefficient has the merit of being readily applicable to field conditions. Thus it can be ex-

[7] V. C. Fishel, "Further Tests of Permeability with Low Hydraulic Gradients," *Amer. Geophysical Union Trans. 1935*, Pt. 2 (1935), pp. 499–503.

pressed, as shown in Figure 5, by the rate of flow, in gallons a day, through each foot of thickness of a stratum in a width of 1 mile, under a hydraulic gradient of 1 foot to the mile, at 60°F.

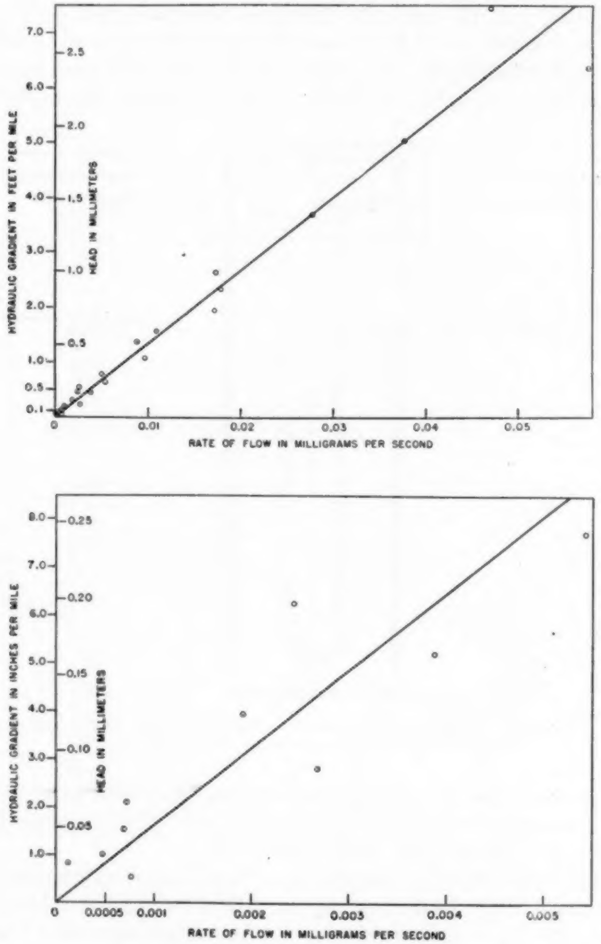

FIG. 3.—Diagram showing results of test by Fishel in 1934 of flow of water through sand under low hydraulic gradients.

Natural earth materials that have been testea ın our laboratory have been found to have coefficients of permeability ranging from

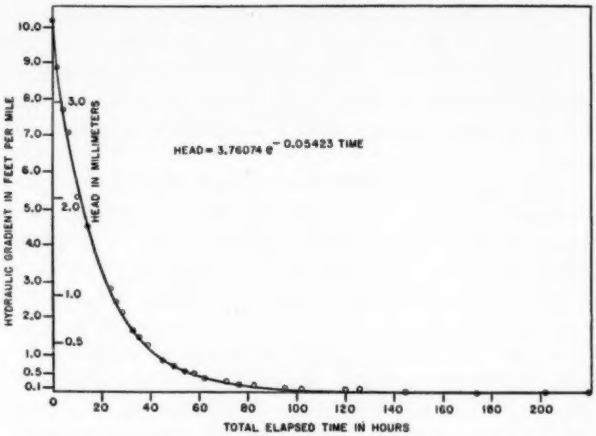

FIG. 4.—Diagram showing same results as those presented in Figure 3 but with elapsed time plotted against hydraulic gradient.

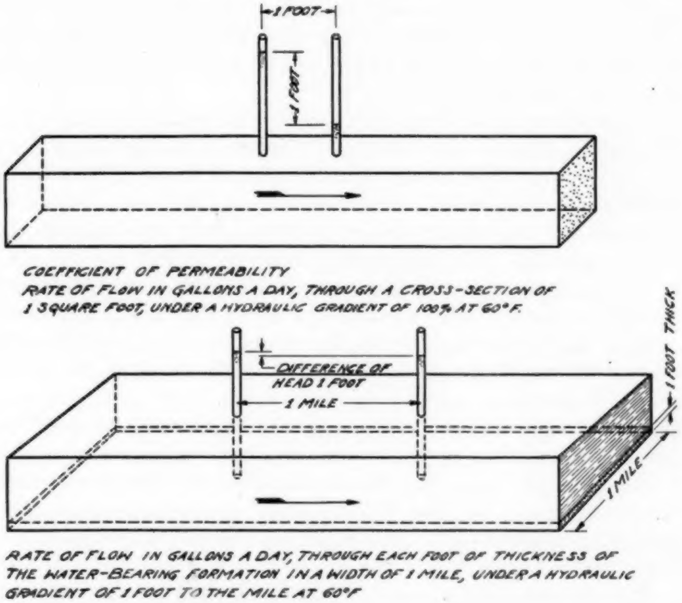

FIG. 5.—Diagrams to illustrate laboratory and field application of the coefficient of permeability used in the hydrologic work of the United States Geological Survey.

about 0.001 to about 90,000; that is, the most permeable material carries water at a rate about 90,000,000 times that of the least permeable material. However, most materials that are sufficiently water-bearing to be utilized by wells, have coefficients that are whole numbers of two or three figures—that is, coefficients ranging between 10 and 1,000.

For testing materials of very low permeability we use some form of apparatus of the non-discharging U-tube type (Fig. 2). In the test which gave the lowest permeability we used a very simple apparatus, consisting essentially of a glass U-tube with provision to prevent evaporation without interfering with the normal atmospheric pressure, but for most samples somewhat more complicated apparatus is required. The lowest permeability yet obtained in our work is that determined by Stearns.[8] The material tested is a fine silt which is nearly impervious but has a porosity of 54 per cent. In the test the column of material was 50 millimeters high and the initial head was 50 millimeters of water. During a test of 133 days, from August 20 to December 31, 1924, the water level in one arm of the tube declined gradually about 7 millimeters and that in the other arm rose about the same distance. Therefore, the average hydraulic gradient during the test was approximately 93 per cent. The permeability computed from these data is about 0.001.

From the porosity of the material used in this test and the rate of percolation, the average velocity of the water during the test was computed to have been about 0.1 foot a year, or about 1 mile in 50,000 years. The experiment shows the very slow but continuous movement of water that may occur through dense material and indicates that water behaves as a fluid under almost extreme limits.

An example of more or less average performance of a moderately productive water-bearing formation is afforded by the Carrizo sandstone in the Winter Garden region of Texas, which, according to the work of W. N. White and his associates, has a coefficient of permeability of about 200 and a porosity of about 40 per cent, giving an average velocity of the water, under a hydraulic gradient of 10 feet to the mile, of about 50 feet a year, or about 1 mile in 100 years. It is somewhat surprising that this slow motion gives a total computed flow of water through a 60-mile section of the formation, about 200 feet thick, of about 24,000,000 gallons a day, or about 27,000 acre-feet a year.

The most permeable natural material that has been tested in our laboratory is a fine gravel with a porosity of 38 per cent, obtained

[8] N. D. Stearns, *op. cit.*, p. 157.

from a well on Long Island. According to the test this gravel has a coefficient of permeability of about 90,000. It may be computed that under a hydraulic gradient of 10 feet to the mile, water would move through this gravel at an average velocity of about 60 feet a day, or 1 mile in about 3 months. Under higher gradients the velocity would obviously be proportionately greater.

A method for determining permeability that is now used in ground-water work in this country is the field method which was described by Günter Thiem,[9] a German hydrologist, in 1906, and which has recently been further studied and developed by L. K. Wenzel,[10] of the United States Geological Survey. In principle this method is the same as that used in laboratory tests of permeability, but it is made on a larger scale and with undisturbed field conditions. A well drawing from a stratum of known thickness is pumped or allowed to flow at a measured rate, and the drawdown is measured in two or more observation wells at known distances from the producing well.

Under ideal conditions, approximate equilibrium is established with constant pumping or flow and water percolates toward the discharging well equally from all directions, the same quantity percolating toward the well through each of an indefinite series of concentric cylindrical sections around the well. The quantity of water, Q, that percolates through any of the concentric cylindrical sections, is equal to PIA, where P is the coefficient of permeability of the water-bearing material, I is the hydraulic gradient, and A is the cross-sectional area of the saturated part of the cylinder. The permeability, P, thus equals $\frac{Q}{IA}$. This fundamental formula is developed by the Thiem method in such a manner that the hydraulic gradient can be determined from the difference in drawdowns in two observation wells and the coefficient of permeability computed directly by the evaluation of Thiem's formula. This formula is as follows, P being the Geological Survey's coefficient of permeability, Q the yield of the well expressed in gallons per minute, a and a_1 the distance of two observation wells from the discharging well, in feet, s and s_1 the respective drawdowns in the observation wells, in feet, and m the average thickness of the saturated water-bearing material at the two wells, in feet.

[9] G. Thiem, *Hydrologische Methoden*, Leipzig, 1906.

[10] L. K. Wenzel, "Recent Investigations of Thiem's Method for Determining Permeability of Water-Bearing Materials," *Trans. Amer. Geophys. Union* (1932), pp 313–17.

———, "Specific Yield Determined from a Thiem's Pumping Test," *Trans. Amer. Geophys. Union* (1933), pp. 475–77.

———, "The Thiem Method for Determining Permeability of Water-Bearing Materials," *U. S. Geol. Survey Water-Supply Paper 679-A* (1936).

$$P=\frac{527.7Q\log\frac{a_1}{a}}{m(s-s_1)}$$

An intensive test to determine the adaptability of the Thiem method was made near Grand Island, Nebraska, by Wenzel in 1931. More than 80 observation wells were constructed at different distances and in several different directions from the pumped well. The drawdowns in these wells were measured periodically during a 48-hour pumping test. It was found that reliable results could be obtained best by substituting in Thiem's formula only drawdowns in observation wells located relatively close to the pumped well—from 40 to 200 feet—because the cone of depression at greater distances from the pumped well had not reached an approximate equilibrium after 48 hours of pumping. Moreover, it was found that each drawdown substituted in Thiem's formula should be the average of the drawdowns at that distance on opposite sides of the pumped well. The coefficients of permeability so computed are given in the following table.

Using the procedure developed from the Grand Island test, Wenzel made two additional tests in 1933—one near Kearney, Nebraska, and the other near Gothenburg, Nebraska. Ten wells were constructed for each of these tests, five on each side of the pumped well. The computations of the coefficient of permeability were made from the data of each test for distances between 50 and 250 feet. For the Kearney test the computed coefficients ranged between 4,010 and 4,290, and for the Gothenburg test between 3,750 and 3,920.

Darcy's law holds to the extent that the movement of water through small openings is a simple laminar or stream-line movement, as was visually demonstrated by the English physicist H. S. Hele-Shaw[11] for openings of both regular and irregular shape (Fig. 6). In each thread of the laminar movements there is an endless procession of molecules of water, following one another in precisely the same path, propelled by the differential pressure that overcomes the friction with the adjacent thread of more slowly moving molecules nearer the wall of the opening. In larger openings and with greater velocity, the friction between adjacent threads causes eddies that retard the

[11] H. S. Hele-Shaw, "Experiments on the Nature of the Surface Resistance in Pipes and on Ships," *Inst. Naval Arch. Trans.* (1897), pp. 145–56; "Investigation of Stream-Line Motion under Certain Experimental Conditions," *Inst. Naval Arch. Trans.* (1898), pp. 21–46; "Stream-Line Motion of a Viscous Fluid," *British Ass'n. Rept.* (1898). See the excellent discussion of the subject by W. C. Unwin under "Hydraulics" in the Encyclopedia Britannica, 11th ed.

forward movement. Hence the flow through larger openings does not increase in proportion to the increase in hydraulic gradient, but, as

COMPUTATION OF COEFFICIENTS OF PERMEABILITY FOR 48-HOUR PUMPING TEST NEAR GRAND ISLAND, NEBRASKA
BY L. K. WENZEL
Pumping rate, $Q = 540$ gallons per minute.

Distant Well a_1 *(Feet)*	*Near Well* a *(Feet)*	*Thickness* m *(Feet)*	*Difference in Drawdown* $s - s_1$ *(Feet)*	*Permeability* P
60	40	96.94	.53	976
80	40	97.14	.91	970
100	40	97.28	1.19	980
120	40	97.40	1.44	969
140	40	97.50	1.63	975
160	40	97.58	1.79	982
180	40	97.65	1.93	987
200	40	97.71	2.07	985
80	60	97.40	.38	962
100	60	97.54	.66	983
120	60	97.67	.91	965
140	60	97.76	1.10	975
160	60	97.84	1.26	985
180	60	97.91	1.40	992
200	60	97.98	1.53	994
100	80	97.73	.28	1,010
120	80	97.85	.53	967
140	80	97.95	.72	982
160	80	98.03	.88	994
180	80	98.10	1.02	1,002
200	80	98.16	1.15	1,005
120	100	98.00	.25	919
140	100	98.09	.44	964
160	100	98.17	.60	978
180	100	98.24	.74	1,000
200	100	98.30	.87	1,003
140	120	98.22	.19	1,023
160	120	98.30	.35	1,035
180	120	98.37	.49	1,040
200	120	98.43	.62	1,043
160	140	98.39	.16	1,050
180	140	98.46	.30	1,071
200	140	98.52	.43	1,043
180	160	98.54	.14	1,053
200	160	98.60	.27	1,038
200	180	98.68	.13	1,000
			Average,	997

has been empirically determined by many experiments, it increases more nearly in proportion to the square root of the hydraulic gradient.

Experiments have shown that the change from laminar flow to turbulent flow occurs in water at a limiting size in tubular openings of about 1/50 inch; that is, smaller tubes are considered to be of capillary size in the sense that the movement of water through them at ordinary temperatures is generally laminar movement, whereas larger tubes are of supercapillary size in the sense that the movement is likely to be of the turbulent type. It should be noted that this figure for the limiting size is only an approximation, and that the actual

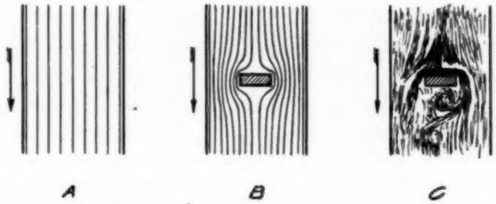

FIG. 6.—Diagrams showing laminar or stream-line flow (*A* and *B*) and turbulent flow (*C*). (In general after H. S. Hele-Shaw.)

limiting size varies with the velocity of the water and also with the temperature of the water, because the temperature affects its viscosity. Moreover, it does not define the limiting size for capillary rise produced by molecular attraction, for water will rise by capillarity in a clean glass tube of this size to a height of nearly $2\frac{1}{2}$ inches. It may again be pointed out that the limiting value of 0.508 millimeter, which has been widely quoted from Van Hise's "Treatise on Metamorphism,"[12] is merely $\frac{1}{50}$ inch converted into the metric system and improperly carried to the third decimal place.[13]

LAW OF MOVEMENTS THROUGH SUBCAPILLARY OPENINGS

Openings which are so small that their space lies entirely within the range of the molecular attraction of their walls are generally said to be of subcapillary size. The movement of water or oil through such extremely small openings is very imperfectly understood, although there has been much investigation that bears on different phases of the subject. It is, however, a subject of great importance to hydrologists and of still greater importance to petroleum geologists and tech-

[12] C. R. Van Hise, "A Treatise on Metamorphism," *U. S. Geol. Survey Monogr.* (1904), pp. 134–46.

[13] Alfred Daniell, *A Text-Book of the Principles of Physics*, 2d. ed. (London, Macmillan & Co., 1885), p. 293. See also O. E. Meinzer, "The Occurrence of Ground Water in the United States, with a Discussion of Principles," *U. S. Geol. Survey Water-Supply Paper 489* (1923), p. 26.

nologists. It doubtless deserves much more thorough and systematic study than it has hitherto received. What is the range of molecular attraction? What force is required to cause water or oil to move through subcapillary openings? What is the rate of such movement and the controlling law? Is a fine-textured but porous clay absolutely impermeable under hydraulic gradients such as exist in nature, or does it permit movement that is very slow but may nevertheless produce important effects in the course of geologic time? For example, in the Dakota artesian basin a stratum of tight plastic shale, somewhat more than 200 feet thick, lies between two water-bearing strata and has for about 50 years maintained a pronounced difference between

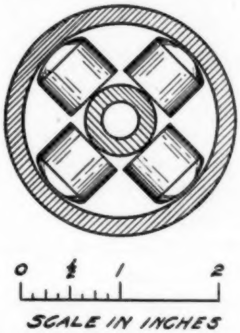

FIG. 7.—Diagram of centrifuge used by A. F. Lebedeff in testing amount of moisture retained in soils against a pull 70,000 times that of gravity. One pound equals 35 tons. Sample with depth of ½ inch equals rock column with thickness of 2,000 feet.

them in artesian head and in the chemical character of the water.[14] This condition demonstrates a high degree of effective impermeability but nevertheless does not prove absolute impermeability.

On the one hand is the evidence of experiments such as that of the Russian hydrologist and soil specialist Lebedeff,[15] who worked in the laboratory of the U. S. Bureau of Soils in Washington, D. C., with a centrifuge that produced a pull 70,000 times that of gravity, 1 pound of matter exerting a pull of 35 tons (Fig. 7). The soil cups in the

[14] O. E. Meinzer and H. A. Hard, "The Artesian-Water Supply of the Dakota Sandstone in North Dakota, with Special Reference to the Edgeley Quadrangle," *U. S. Geol. Survey Water-Supply Paper 520* (1925), pp. 79–80.

[15] A. F. Lebedeff, "Determination of the Maximal Molecular Water Capacity of the Soil by Means of Centrifuging and Characteristics of Mechanical Properties of Soil by Determining the Maximal Molecular Water Capacity." Printed in English in the Russian publication which in English is called *Pedology* (1928), pp. 49–69.

centrifuge were a little less than ½ inch in height. If the saturated soil columns in the cups were ⅓ inch high they exerted about the same pressure as the weight of a formation of similar material 2,000 feet thick. The tests, however, showed that the water in the clays and loams was largely held against this great force.

WATER HELD BY SOIL AFTER CENTRIFUGING IN TESTS BY A. F. LEBEDEFF

	Water Content, in Per Cent of Dry Weight of Sample		
	400 g.	*1,800 g.*	*70,000 g.*
1. Clay	54.1	32.0	31.7
2. Clay	50.8	33.4	32.4
3. Clay loam	41.2	24.3	22.5
4. Clay	40.5	23.6	23.4
5. Clay loam	31.1	18.1	16.5
6. Silt loam	34.2	14.1	13.5
7. Silt loam	21.7	6.9	5.9

On the other hand is the evidence of the compaction of shale under increasing load, as shown in the studies of Athy,[16] with the corrollary that the contained water was by some process forced out of the formation; also the evidence of tests made by different investigators in which water and oil have been squeezed out of clays by the direct application of great pressure.

In studying the problem of the compression of water- or oil-bearing materials, it is essential to distinguish between the force required to overcome the resistance of the solid particles and the force required to overcome the resistance of the contained liquid. In relatively coarse-grained materials the large solid particles have great resistance to compression, whereas the liquid moves readily through the large openings; in very fine-grained materials, however, the small particles, generally of angular and irregular shape, offer much less resistance to compression, whereas great force is required to move the adhering liquid. Moreover, it should be remembered that the movement of a liquid out of or through a formation requires a hydraulic gradient; that is, the available pressure is distributed over the entire path of the moving liquid. Consequently, the thickness of a formation becomes a factor in the problem as well as the texture and compressive force. Consequently, also, the results obtained from a given pressure on a small sample may not be directly applicable to a thick formation of similar material.

[16] L. F. Athy, "Density, Porosity, and Compaction of Sedimentary Rocks," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14 (1930), pp. 1–24.

DIRECTION OF MOVEMENT

The following elemental generalizations can be made in regard to the movement of ground water, on the broad basis of all the work that has been done on the subject by hydrologists.

1. Ground water tends to move from a position of high pressure, along a hydraulic gradient, to a position of lower pressure.

2. The chief structure controlling the direction of movement is the stratification of the rocks. Therefore, a map showing contours of the piezometric or pressure-indicating surface of any water-bearing stratum shows the general direction in which the water is moving, and also, to a great extent, its source and destination.

3. Water-bearing strata generally have hydraulic gradients, and therefore their water is generally in motion. However, essentially static conditions also exist on account of effective barriers, especially in the deep-lying formations.

4. The movement of ground water generally starts at a water table at a relatively high altitude, the level of the water table being maintained approximately by recharge of meteoric water. The movement generally leads to a water table at a lower altitude where the ground water is discharged through springs and by transpiration and evaporation from the soil, but the movement may lead to discharge through submerged openings into lakes or into the ocean.

5. Movement of water across the strata is generally much slower than the movement along the strata. However, it is not exceptional, but occurs very generally throughout the zone of saturation. It is important in some places in recharging buried formations and building up artesian pressure in them, and in other places in providing discharge of artesian water, which reduces artesian pressure but may also freshen the water in formations that have no outlet along the strata. Thus the system of hydraulic gradients in the zone of saturation is not so simple as it is in many of the ordinary artificial hydraulic structures, for it is a three-dimensional system. The ground water only a few feet or even a few inches below the water table may have a pressure head considerably above or below that at the water table. Therefore in ground-water studies it is essential to distinguish between the water table itself and an indefinite number of piezometric surfaces which represent more or less adequately the pressure conditions that control the direction of movement of the water throughout the zone of saturation.[17]

[17] O. E. Meinzer, "Outline of Ground-Water Hydrology, with Definitions," *U. S. Geol. Survey Water-Supply Paper 494* (1923), pp. 37–42.

LAG OF MOVEMENT BEHIND CAUSAL PRESSURE CHANGES

Although ground water everywhere moves in response to hydrostatic pressure, considerable time may be required for the pressure effects to be transmitted, especially where great changes occur, as when wells are opened and closed. The feature of lag is of great significance in ground-water problems and doubtless also in problems of the movement and recovery of oil. The lag is due chiefly to the transfer of water or oil that is involved.

Under water-table conditions the cone of depression of a producing well develops slowly because its development involves the removal of much water. In the elaborate test made by Wenzel[18] in the Platte Valley, Nebraska, the rim of the cone of depression reached 500 feet from the producing well in 2 hours, 900 feet in 6 hours, and about 1,200 feet in 12 hours.

Under artesian conditions the cone of depression develops much more rapidly than under water-table conditions, because the removal of less water is involved. In tests made by R. M. Leggette and G. H. Taylor[19] in the artesian basin of the Ogden Valley, Utah, the first effects of pressure changes were transmitted at different rates according to varying conditions, showing that the entire problem is complex. However, in all cases the transmission occurred at a much more rapid rate than in the test by Wenzel under water-table conditions. Thus the opening of an artesian well affected the head in an observation well 2,850 feet distant in 7 minutes; the opening of another artesian well 3,850 feet distant affected the head in the observation well in 57 minutes. In other tests changes of pressure were transmitted a distance of about 2 miles in 3 to 13 hours.

The rate of progression of pressure effects in water in a permeable but perfectly rigid rock formation encased in perfectly rigid and impermeable confining beds would doubtless be very rapid, although not instantaneous. It can be computed from the data obtained in the tests of many artesian wells that the cones of depression produced under artesian conditions involve the transfer of much more water than would be required merely by the expansion of the water as a result of its volume elasticity.[20]

The storage capacity of the large underground reservoirs formed

[18] L. K. Wenzel, "The Thiem Method for Determining Permeability of Water-Bearing Materials," *U. S. Geol. Survey Water-Supply Paper 679-A* (1936).

[19] R. M. Leggette and G. H. Taylor, "The Transmission of Pressure in Artesian Aquifiers," *Amer. Geophys. Union Trans., 1934,* Pt. 2 (1934), pp. 409–13.

[20] O. E. Meinzer, "Compressibility and Elasticity of Artesian Aquifers," *Economic Geology,* Vol. 23 (1928), pp. 263–91.

by the principal artesian formations is so great that even with a moderate compression resulting from removal of the expansive force of artesian pressure they may yield great quantities of water taken from storage. Thus the available data in regard to the Dakota sandstone seem to lead to the conclusion that the great quantity of water discharged by several thousand flowing wells supplied by this sandstone in the last half century was in considerable part derived from storage through compression rather than from recharge or lowering of the water table in the outcrop area.[21] For this reason the permanent safe yield of an artesian formation may easily be overestimated unless its capacity for transmitting water is determined.

In the recovery of oil, greater lag may generally be expected than in the recovery of artesian water because of the greater volume elasticity of the fluid and the evolution of gas that may replace the oil in some of the interstices. The quantity of liquid removed from storage is also likely to be greater because of the greater pressure changes that are generally produced in oil-well production. Thus with respect to the development of cones of depression, oil wells may be more like water-table wells than like artesian wells. In all considerations of a so-called water drive the modifying effects of lag should not be overlooked.

STATIC CONDITIONS

In most of the formations that contain fresh water the water is moving from intake to discharge areas but in many of the salt-water formations static or nearly static conditions doubtless prevail. The occurrence of oil in recoverable quantities virtually implies essentially static conditions in so far as the oil is concerned. Essentially static conditions of water or oil may conceivably be found in underground reservoirs or conduits that are completely sealed, that are sealed at one end, or that contain fluids which differ in specific gravity.

A sealed reservoir is a body of porous rock that is completely encased by impermeable material which isolates the fluid in this porous rock from the fluid on the outside. It is indicated chiefly by an original pressure that is either lower or higher than can be attributed to the hydrostatic pressure of the water in the zone of saturation, due account being taken of the differences in altitude of the intake areas of successive strata with intervening confining beds and the loss of head of ground water in motion because of friction. A pressure that is higher than can be explained as hydrostatic pressure might be due

[21] O. E. Meinzer and H. A. Hard, "The Artesian-Water Supply of the Dakota Sandstone in North Dakota, with Special Reference to the Edgeley Quadrangle," *U. S. Geol. Survey Water-Supply Paper 520* (1925), pp. 90–93.

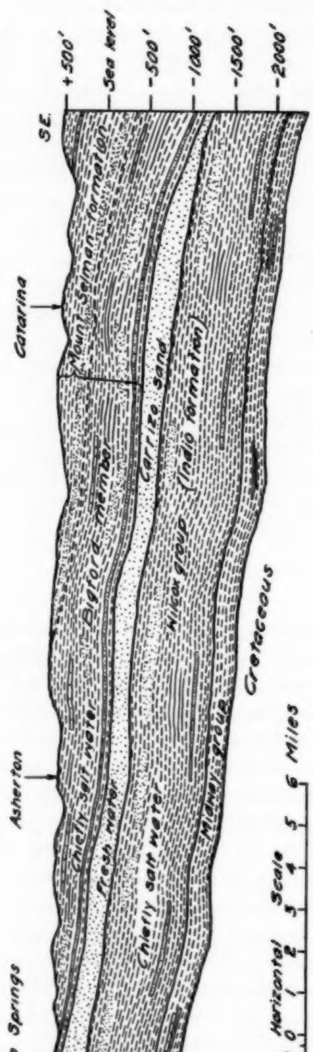

FIG. 8.—Geologic cross section in Winter Garden area, in Texas, showing occurrence of fresh and salt water.

either to incompetence of the effectively encased rock to support the load of deposits that have accumulated over it since its encasement, or to the evolution of gas within the sealed reservoir. Data that indicate abnormally low or abnormally high pressures should be carefully checked and studied before they are interpreted as evidence of independence from hydrostatic pressure. Pressures obtained at or near the bottom of an oil or gas well are, of course, much more subject to interpretation than pressures obtained at the top of the well. Pressures that appear to be lower than the hydrostatic pressure are likely not to be the original pressures, but rather the pressures after drawdown has taken place. Pressures that appear to be higher than the hydrostatic pressure are perhaps more convincing, but due account should always be taken of the possibility of high artesian pressure in a deep-lying formation transmitted from a distant source at a high altitude. On the other hand, records of abnormal pressures should not be discounted merely because they do not fit into preconceived theories, as they might lead to the discovery of significant conditions that are not now understood.

If an artesian formation between impermeable confining beds is sealed at its lower end, a condition of static equilibrium may be established and there may be essentially no movement of the water or oil which it contains until this condition is disturbed by drilling. This is considered to be more or less the condition in the East Texas Oil Field, caused by an unconformity that cuts out the oil-bearing formation toward the east. It may be pointed out that this explanation postulates that originally there was a level piezometric surface and that the hydraulic gradient toward the east was developed after production began.

Many of the formations that yield salty water either have very sluggish movement, or movement is effectively prevented by the pinching out of the formation or the existence of some other barrier. An example of this condition is apparently afforded by the salty water in the Winter Garden area, in Texas (Fig. 8), in strata above the Carrizo sandstone, which yields large quantities of fresh water and probably for a long time has carried water from its outcrop to the sea. Large springs of salty water are, however, likely to indicate the existence of a salt deposit that furnishes a perennial supply of salt to ground water that is in motion and eventually emerges through the springs.

The law of balance in a coastal area between the fresh ground water and the salt water of the sea was announced by Badon Ghyben in 1889 and was rediscovered and more thoroughly described by Herz-

berg in 1901.[22] According to this law, if a formation has water-table conditions and is accessible to the sea water, the sea water may enter the formation, but will remain at such a depth that the overlying column of fresh water will balance a column of the heavier sea water extending to the same depth. Thus if the fresh ground water has a specific gravity of 1 and the sea water a specific gravity of 1.025, the contact between the sea water and the overlying fresh water at any place is depressed 40 feet below sea-level for every foot that the water table stands above sea-level. If the surface of the sea remained at a constant level and recharge from rainfall were at a uniform rate, the surface forming the contact between the fresh and the salt water would remain in the same position and the salt water would remain motionless while the fresh water would percolate toward the sea in the same manner as if the contact were an impermeable surface. The ebbing and flowing of the tides and the seasonal variation in recharge, however, continually disturb the balance between the fresh and salt water and cause the contact surface to fluctuate. By this natural fluctuation, as well as by the diffusion of the salt, the sharp contact be ween fresh and salt water is destroyed and a considerable transition zone of brackish water is created.

If a well is pumped and a cone of depression is developed under such conditions, the salt water will rise below the well and will form an upright cone, theoretically having a height about 40 times the depth of the cone of depression. If pumping is continued at a constant rate without change in the cone of depression, the contact surface theoretically remains stationary and the salt water remains motionless while the fresh water percolates from all directions toward the well. If, however, the rate of pumping is increased or, because of depletion of the supply, the water table is further depressed, the apex of the salt-water cone may reach the bottom of the well, salt water may be drawn into the well, and movement in the salt-water zone may be inaugurated. The process of skimming fresh water from above the salt water is conducted on a large scale on the island of Maui, in the Territory of Hawaii, where 40 million gallons a day is pumped from one shaft that extends only a short distance below the water table and has tributary tunnels just below the water table.

The coning produced by oil wells is essentially the same phenomenon as the coning of water wells. It is less pronounced for the same amount of drawdown because of the greater difference in specific

[22] For a discussion of this principle and the history of its development see J. S. Brown, "A Study of Coastal Ground Water, with Special Reference to Connecticut," *U. S. Geol. Survey Water-Supply Paper* 537 (1925).

gravity of the contact liquids, but the drawdown is likely to be much greater in oil wells than in water wells. There are doubtless also important differences in the mixture of the liquids produced by the fluctuations of the contact surfaces.

Wherever an artesian formation dips toward the sea and has a submarine outcrop it forms one limb of a huge U-tube, the other limb of which is the sea. This is the general condition on the Atlantic and Gulf Coastal Plains[23] and to some extent along the Pacific Coast. It is also the condition in the artesian basins of Oahu.[24] In the artesian area shown in Figure 9, the head was originally about 36 feet with reference to sea-level. As the specific gravity of the sea water in that region is about 1.024, it was inferred that the confining bed extends to about 1,500 feet below sea-level and that the fresh artesian water originally occupied the formation to that depth and there discharged into the sea. With extensive pumping of artesian water, the water level was depressed and consequently the salt water rose until it reached the bottoms of some of the deepest wells. If the upper lip of the confining bed had been appreciably less than 36 feet above sea-level, the original ground-water level would presumably not have been high enough to depress the salt-water contact to the level of the submarine outlet. Therefore the fresh water would have been discharged through large springs along the upper lip of the confining bed and the water in the deeper parts of the formation would have been nearly motionless. This is in fact the explanation of the large springs near Pearl Harbor, as shown by the extensive investigations of Stearns.

Figure 9 illustrates in simplified form the problem of salt-water balance in the artesian formations in the Atlantic and Gulf Coastal plains. Whether active or static conditions exist depends on the artesian head and the correlative depth of the submarine outcrop. If the head is relatively high or the submarine outcrop is relatively near sea-level, active conditions prevail. Under these conditions there is a hydraulic gradient, the water is percolating downward through the formation, the soluble salts have generally been removed, and the artesian water is relatively free of mineral matter. Conversely, if the head is low or the submarine outcrop is at great depth, static condi-

[23] See, for example, D. G. Thompson, "Ground Water Supplies of the Atlantic City Region," *New Jersey Department of Conservation and Development Bull. 30* (1928), and V. T. Stringfield, "The Piezometric Surface of Artesian Water in the Florida Peninsula," *Amer. Geophys. Union Trans.* (1935), pp. 524–29.

[24] John McCombs, "Methods of Exploring and Repairing Leaky Artesian Wells on the Island of Oahu, Hawaii," *U. S. Geol. Survey Water-Supply Paper 596* (1927), pp. 7–8 and Fig. 2. See also H. T. Stearns and K. N. Vaksvik, "Geology and Ground-Water Resources of the Island of Oahu, Hawaii," *Terr. Hawaii Div. Hydrography Bull. 1* (1935), pp. 239–68.

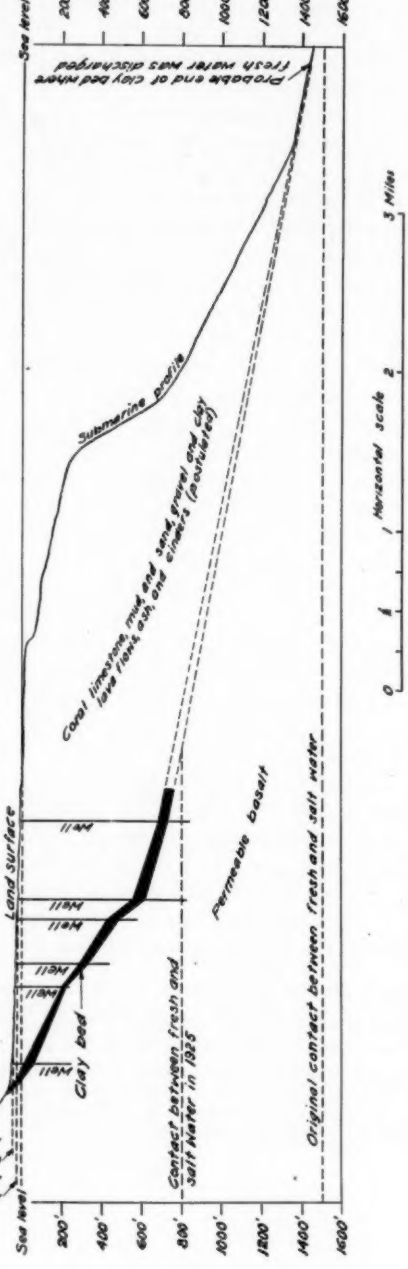

FIG. 9.—Geologic cross section of artesian area at Honolulu, showing relation of fresh water to salt water (after McCombs).

tions prevail. The lower part of the formation is plugged by salt water and there is no hydraulic gradient, no seaward percolation, and no leaching out of the soluble salts except as artesian water may escape through the overlying confining beds.

An artesian formation in a syncline likewise has a U-tube structure. It may have static conditions if it was originally filled with salt water and has never had enough head of fresh water to expel the salt water. Obviously such conditions are the converse of those under which oil and gas accumulate in anticlines. They are apparently the conditions that exist to a great extent in the deep-lying Paleozoic formations of the interior of the United States, which are largely occupied with salty water.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 20, NO. 6 (JUNE, 1936), PP. 726-735, 1 FIG.

SALT-DOME STATISTICS[1]

GEORGE SAWTELLE[2]
Houston, Texas

ABSTRACT

The purpose of this compilation is to show in a brief tabulated form some of the more important data on discovery, geology, and production of the Gulf Coast salt domes.

NUMBER AND LOCATION

One hundred and forty-one salt domes are known in the Texas-Louisiana Gulf Coast (Fig. 1).

Three of the domes are located in the Rio Grande province. Seventy-seven lie between Jackson County and the Sabine River in a province which will probably be connected with the domes in the East Texas embayment by future discoveries,[3] and sixty-one lie in the Louisiana coastal district. Connection of the latter domes with those of the interior of Louisiana is partially established by Pine Prairie and by the Cheneyville discovery.

YEAR OF DISCOVERY

Although there were sixteen coastal salt domes known as such before 1901, their commercial importance for oil and gas dates from the discovery of Spindletop in that year. The number of domes discovered each year by drilling is shown in Table I.

TABLE I

DISCOVERY OF DOMES BY YEARS*

Year of Discovery	*Texas*	*Louisiana*	*Total*
Known long before 1901	7	9	16
1901	4	2	6
1902	2	1	3
1903	2	0	2
1904	2	0	2
1905	2	0	2

* From the date of the Spindletop discovery, which showed the significance of surface indications, it is interesting to note the decline in discovery rate until 1924, when geophysics was introduced.

[1] Manuscript received, March 7, 1936.

[2] President, Kirby Petroleum Company. Much of the contained information was furnished by Donald C. Barton and L. P. Teas, of the Humble Oil and Refining Company; Alexander Deussen, consulting geologist; J. C. Miller, of The Texas Company; and Paul Weaver, of the Gulf Production Company. The tables were prepared by L. Thorold, of the Kirby Petroleum Company.

[3] Marcus A. Hanna, "Geology of the Gulf Coast Salt Domes," *Problems of Petroleum Geology* (Amer. Assoc. Petrol. Geol., 1934), p. 631.

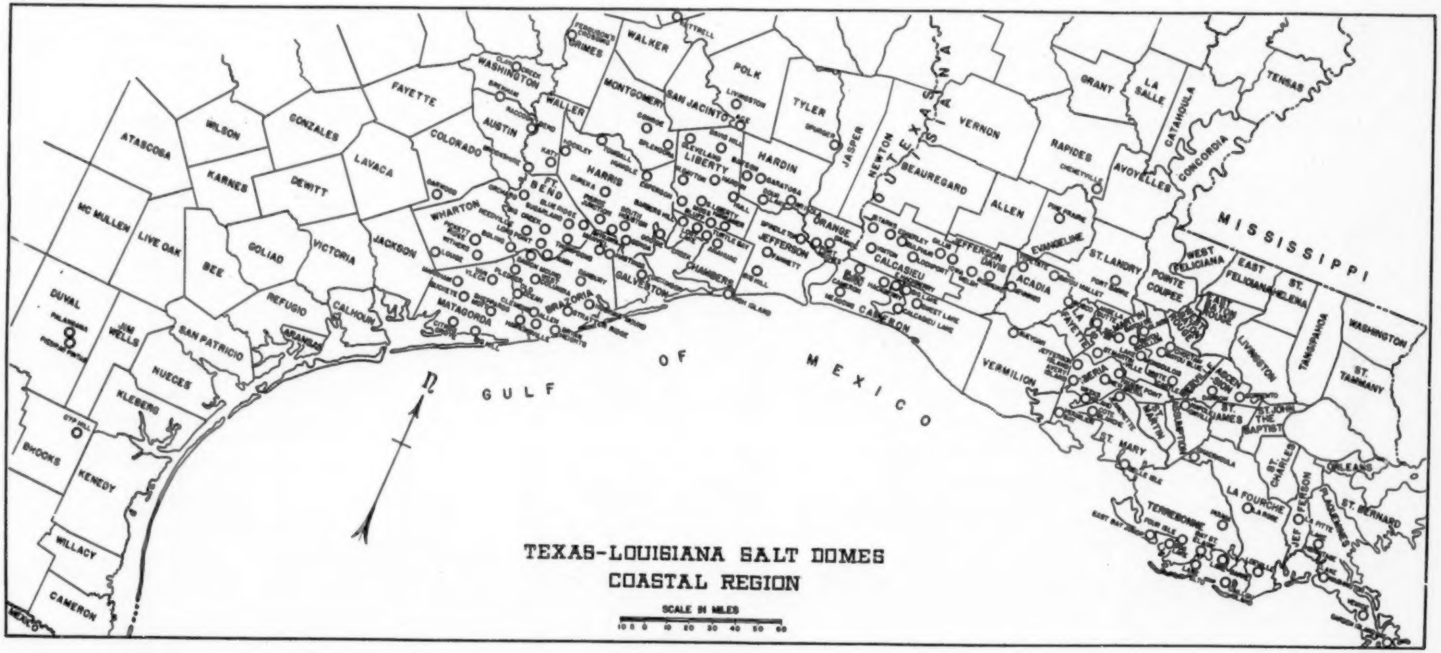

FIG. 1—Texas and Louisiana salt domes.

TABLE I (*Continued*)

1906	0	1	1
1907	1	0	1
1908	2	1	3
1909	0	0	0
1910	0	0	0
1911	1	1	2
1912	0	0	0
1913	2	0	2
1914	0	0	0
1915	1	0	1
1916	1	0	1
1917	0	2	2
1918	0	0	0
1919	0	0	0
1920	0	0	0
1921	0	0	0
1922	1	0	1
1923	1	0	1
1924	2	1	3
1925	7	2	9
1926	3	8	11
1927	2	8	10
1928	6	9	15
1929	4	2	6
1930	1	2	3
1931	3	0	3
1932	3	0	3
1933	5	3	8
1934	10	1	11
1935	5	6	11
1936 (January)	0	2	2

MEANS OF DISCOVERY

The discovery of many salt domes has been influenced by numerous factors. Herewith are shown the features or agencies which led to the discovery of the domes.

Features or Prior Work Leading to Discovery	*Texas*	*Louisiana*	*Total*
Mound	16	10	26
Paraffine dirt	10	10	20
Gas seeps	17	16	33
Sulphur and/or sour water	13	1	14
Oil seeps		2	2
Gas and/or oil in water wells	3	3	6
Surface geology	9	1	10
Subsurface geology	2		2
Torsion balance	26	7	33
Refraction	14	31	45
Reflection	14	10	24
Pendulum	1		1
Magnetometer	2		2
Wildcat	1		1

SURFACE

Nineteen salt domes have been found in marshes, nine have been found in lakes, and eleven have been found in marshes and lakes.

TABLE II

Coastal Texas Salt Domes

FIELD AND COUNTY	SURVEY	CURRENTLY CONTROLLING COMPANIES	INDICATIONS LEADING TO DISCOVERY	YEAR OF DISCOVERY (Proof of structure or discovery of oil or gas)	TO SHALLOWEST DRILLED DEPTH IN FEET BELOW SURFACE		TOPOGRAPHIC EXPRESSION		SITUATION		PRODUCING HORIZON					PRODUCTION THROUGH 1935 IN BARRELS	DEEPEST WELL DRILLED TO END OF 1935		REMARKS
					CAP ROCK	SALT CORE	HEIGHT OF MOUND IN FEET	CENTRAL DEPRESSION	IN MARSH	IN LAKE OR BAY	CAP ROCK	PLIOCENE	MIOCENE	OLIGOCENE	EOCENE		FORMATION	DEPTH OF HOLE IN FEET	
EAST OF JACKSON COUNTY																			
ACE, Polk	F.A.Menard	Miscellaneous	Gas seeps & torsion balance	1933											T	27,574	Lower Saline Bayou	7438	Gas and distillate. Not the same as the Ace prospect of former years.
ALLEN, Brazoria	J.G.& G.W.McNeel	Mills Bennett	Torsion balance	1925	760	1380							T			78,526	Miocene	5958	Overhang production
ANAHUAC, Chambers	H.& T.C.RR.Co. Sec. 58	Humble	Reflection & torsion balance	1935		?								P		353,554	Frio	6746	
ARIOLA, Hardin	E. Ariola	Republic & Houston Oil	Refraction	1932		3989							T	M		1,070,000	Upper Saline Bayou	6743	Cap rock reported
BARBERS HILL, Chambers	R. Griffith	Miscellaneous	Mound, Gas seeps & paraffin dirt	1902*	350	1000	45	x			T	T	S	P		51,315,000	McElroy	6148	Overhang production
BATSON, Hardin	J. Milhome	Miscellaneous	Gas seeps & paraffin dirt	1903	1080	2050	6				P	S	P	S	M	37,000,000	Upper Saline Bayou	6502	
BIG CREEK, Fort Bend	Michael Young	Miscellaneous	Sulphur water	1922	450	645						T	M	M		8,500,000	Jackson	5536	Little sulphur produced
BIG HILL, Jefferson	S. Eaton	Stanolind & Houston Oil	Mound	1901*	200	Below 1600	30				T	T	T	T		13,653	Vicksburg	7600	Produced 1923-24 only. Small producers
BIG HILL, Matagorda	I. Ingram	Texas Gulf Sulphur	Mound & sulphur water	1901*	625	1300					T		S			210,906	Miocene	3803	Produced oil 1904-08 only. Sulphur produced
BLUE RIDGE, Fort Bend	J.Poitevent No.3	Miscellaneous	Mound	1903	143	230	25	x					M	M		10,000,000	Jackson	6189	
BOLING, Fort Bend & Wharton	S.F.Austin	Miscellaneous	Sulphur water in water wells	1903	383	975					T		M	S		5,000,000	Vicksburg	5546	Sulphur produced
BRENHAM, Austin & Washington	S.M.Williams	Miscellaneous	Gas seeps & oil in water well	1915	800	1150							T		T	333,476	Sparta	3577	
BROOKSHIRE (SAN FELIPE), Austin & Waller	John McFarland	Miscellaneous	Torsion balance & refraction	1927	3218	4755								T		12,623	McElroy	7715	One well in Upper Saline Bayou, total depth 4824 feet in salt.
BRYAN HEIGHTS, Brazoria	G. Gilland	Texas & Freeport Sulphur	Mound	1901*	680	1136	20										Miocene	5260	Abandoned sulphur mine, 4 to 5 million tons produced.
HOCKLEY, Matagorda	J.C.Keller	United North & South	Surface geology & magnetometer	1931										S		519,348	Frio	9457	
CITRUS GROVE, Matagorda	J.J.Criswell	Continental	Torsion balance & reflection	1934		?											Oligocene (heaving shale)	6995	Gas shows in wells
CLAY CREEK, Washington	J.F.Perry	Sun	Surface geology	1926	1800	3160							M		M	3,000,000	Wilcox	5517	
CLEMENS, Brazoria	R. Cummings	Miscellaneous	Torsion balance	1925	530	1380											Miocene	6319	
CLEVELAND, Liberty	John Pleasants	Gulf	Pendulum	1933		?									S	414,668	Claiborne	8734	
CONROE, Montgomery	Theo. Slade	Miscellaneous	Wildcat	1931		?									P	57,000,000	Lower Saline Bayou	8011	
DAMON MOUND, Brazoria	John T. Mills	Miscellaneous	Mound, paraffin dirt & sulphur dirt	1901*	60	529	76					T	M	M		9,000,000	Vicksburg	8112	
DANBURY, Brazoria	M. Shepard	Shell & Humble	Refraction	1929	[illegible]	5221						T	T			3,612	Oligocene	7495	
DAVIS HILL, Liberty	N.de los Santos Coy	Miscellaneous	Mound & surface geology	1905	1021	1370	170						T				Oligocene	5165	

TABLE II (*Continued*)

DICKINSON, Galveston	W.E.Wilson	Humble & Pure	Torsion balance & reflection	1934		?								P		397,432	Frio	9360	
STEVENSON, Liberty	D.L.Eckernot	General Crude	Torsion balance	1926	7838	7383							M	M	T	3,500,000	Upper Saline Bayou	7386	In salt
EUREKA, Harris	E.Eisenmann	Miscellaneous	Torsion balance	1934											T	4,622	Cockfield	8070	Gas and distillate
FANNETT, Jefferson	W.H.Smith	Gulf	Refraction	1925	670	2200							M	S		1,900,000	Frio	6661	
FERGUSON'S CROSSING, Grimes	G.W.Seaton	Miscellaneous	Surface geology, refraction & magnetometer	1933	3820	4040											Wilcox	6131	In salt. Siderite cap rock
GARWOOD, Colorado	I.& G.N.RR.Sec.44	Miscellaneous	Surface geology & torsion balance	1933											T	2,024	Lower Saline Bayou	6766	Produced oil 1933 only
GENOA, Harris	A. Whitlock	Humble & West Prod.	Torsion balance	1929		?							T				Frio	7777	Small amount of gas
GOOSE CREEK, Harris	Wm.Scott	Miscellaneous	Gas seeps & paraffin dirt	1907		?						S	P	P		74,000,000	McElroy	6975	
HANKAMER, Liberty	H.& T.C.RR.Co.Sec.37	Gulf	Torsion balance	1926	7535	7666							P	S		3,500,000	Jackson	7681	In salt
HARDIN (MOSS HILL), Liberty	J.Robeson	Miscellaneous	Sub-surface geology	1934											S	54,584	Upper Saline Bayou	7511	
HASTINGS, Brazoria	A.C.H.& B.RR.Sec.2	Stanolind & Humble	Reflection	1934										P	T	617,493	Oligocene	6792	
HAWKINSVILLE, Matagorda & Brazoria	Thomas Williams	Pan	Refraction	1925	95												Miocene	9093	Salt overhang
HIGH ISLAND, Galveston	Martin Duncan	Stanolind	Mound	1901*	150	1300	22				T	T	P			11,000,000	Marginulina	6275	Overhang production
HOCKLEY, Harris	S. Everett	Miscellaneous	Gas seeps, sour water & paraffin dirt	1902	99	1109	20				T			T		16,451	Caddell	7063	Salt mined
HOSKINS MOUND, Brazoria	Henry Austin	Texas & Freeport Sulph.	Mound	1904	623	1150	22				S	T				31,755	Miocene	3197	Sulphur produced. Produced oil 1904-07 only.
HULL, Liberty	J. Devore	Miscellaneous	Mound, gas seeps & sulphur water	1908	260	650	17				T	T	P	P	P	80,000,000	Lower Saline Bayou	6676	
HUMBLE, Harris	W.B.Adams	Miscellaneous	Gas seeps, paraffin dirt & sour water	1905	954	1200	15				P		P	P	M	120,000,000	Lower Saline Bayou	6181	
KATY, Waller	J.M.Bennett Sec.100	Miscellaneous	Torsion balance & reflection	1935		?									S		Lower Saline Bayou	7647	Gas well
KITTRELL, Houston	C. McEllis	Miscellaneous	Surface geology	1934	2979	3855									M	416,835	Wilcox	3974	
LIVINGSTON, Polk	A. Viesca	Miscellaneous	Torsion balance	1932		?									M	2,000,000	Upper Saline Bayou	5596	
LONG POINT, Fort Bend	H.& T.C.RR.Sec.66	Gulf	Torsion balance & refraction	1924	550	930											Jackson	6321	Sulphur produced
LOST LAKE, Chambers	Lost Lake	Pure	Refraction	1928	3275	5430				x			S	S		773,264	Frio	7471	In salt.
LOUISE, Wharton	Morris & Cummings	Pure	Refraction	1928										M		594,843	Vicksburg	8871	(Correctly indicated in 1924 by torsion balance, but test did not drill deep enough by a few hundred feet.
MANVEL, Brazoria	Harvey Little	Texas	Torsion balance	1929		?							P	P		4,000,000	Vicksburg	7648	
MARKHAM, Matagorda	Wm. Madden	Miscellaneous	Gas seeps	1908	1380	1417	3				T	S	M	M		5,000,000	Vicksburg	6044	
MOSS BLUFF, Chambers & Liberty	H.D.Labadie	Gulf, Humble & Texas Gulf Sulphur	Refraction	1926	591	1160					T			S		179,835	Vicksburg	7375	
HYLAWA, Harris	W.B. Walker	Miscellaneous	Torsion balance	1928		?							M	M		1,000,000	Whitsett	7355	
NASH, Fort Bend	H.E.Cleveland	Miscellaneous	Sulphur water & torsion balance	1924	620	950							M	M		1,600,000	Vicksburg	6800	
THEWVILLE, Fort Bend	H.& T.C.RR.Sec.25	Miscellaneous	Torsion balance	1929													Vicksburg	6889	Oil and gas shows in wells
NORTH DAYTON, Liberty	H.& T.C.RR.Sec.119	Miscellaneous	Gas seeps	1904	580	800					T	T	M	M		2,000,000	Upper Saline Bayou	5700	
OLD OCEAN, Brazoria	C. Moore	Harrison & Abercrombie & Atlantic	Reflection	1934		?										122,000	Frio	8651	A perennial prospect on basis of surface indication long before days of geophysics.
ORANGE, Orange	Wm. Dyson	Miscellaneous	Gas seeps & paraffin dirt	1913		?						S	P	M		31,700,000	Oligocene	6399	

TABLE II (Continued)

ORCHARD, Fort Bend	James Frazier	Gulf	Refraction	1925	285	375				S	T		S	P		3,000,000	Upper Saline Bayou	6757	
PICKETT RIDGE (PIERCE), Wharton	F. Martinez	Texas	Sub-surface. geol., torsion balance & reflection	1935										M		46,094	Vicksburg	6546	
PIERCE JUNCTION, Harris	I.& G.N.RR, Sec. 47	Miscellaneous	Gas seeps & paraffin dirt	1901	630	950	8						P	M		29,000,000	Vicksburg	7000	
PLEDGER, Brazoria	W. Carson	Danciger & Humble	Reflection	1932										S		17,088	Frio	8115	(Gas and distillate in salt (Drilled on gas seeps and paraffin dirt before 1920, and drilled on poor torsion balance indication in 1925.
PORT NECHES, Orange	Mary E. Bell No. 142	Texas	Refraction	1928	no	7250							P	M		3,400,000	Vicksburg	7850	
RACCOON BEND, Austin & Waller	W.C. White	Humble	Gas in water wells & sulphur water	1928		†							P		P	15,000,000	Lower Saline Bayou	7061	
SARATOGA, Hardin	M.E. Hopkins No. 142	Miscellaneous	Gas seeps, sour water & paraffin dirt	1901	1500	1900					T	T	P	T		27,700,000	Upper Saline Bayou	6275	
SHEPPARDS MOTT, Matagorda	D. McCarthy	Cockburn	Mound & refraction	1925		†	20							T			Oligocene	6151	Oil shows in wells. Drilled previously to 1917 on basis of topography.
SOUR LAKE, Hardin	Stephen Jackson	Miscellaneous	Gas & oil seeps & sour water	1901	666	719	10	x			P	T	P	S	M	77,000,000	Upper Saline Bayou	7914	
SOUTH HOUSTON, Harris	H.T.& B.RR, Sec. 5	Stanolind	Reflection & torsion balance	1934	no	4662							M	M		71,654	McElroy	6489	
SOUTH LIBERTY, Liberty	H.O. White	Miscellaneous	Gas & oil seeps & sulphur water	1902	320	460	18				T		S	P	T	14,800,000	Upper Saline Bayou	5174	
SPINDLE TOP, Jefferson	J.A. Veatch	Miscellaneous	Mound, gas seeps & sour water	1901	700	1200	10				P	S	P	M		122,000,000	Vicksburg	6749	
SPLENDORA, Montgomery	Walker Co. Schl. Ld.	Standard of Kansas	Reflection	1934											S	999	Cockfield	6875	Gas and distillate
SPURGER, Tyler	A. Sterne	Republic & Houston	Torsion balance & reflection	1931		†									T		Sparta	6776	Gas well
STRATTON RIDGE, Brazoria	J. H. Gross	Miscellaneous	Mound & sulphur water	1913	850	1250	15						T			12,214	Vicksburg	7624	Produced oil 1922-24 and 1932-33 only.
SUGARLAND, Fort Bend	Wm. Stafford	Humble	Refraction & torsion balance	1927	3500	4880								P		83,000,000	Vicksburg	4471	
THOMPSONS, Fort Bend	John Rabb	Humble, Gulf & Texas	Torsion balance	1930		†							P	P		18,000,000	Vicksburg	6879	
TOMBALL, Harris	Joseph House	Humble & Magnolia	Surface geology & torsion balance	1933		†									M	3,000,000	Lower Saline Bayou	7428	
TURTLE BAY, Chambers	S. Burney	Stanolind & Texas	Reflection & torsion balance	1935		†								M		2,850	Marginulina	6626	
VAN VLECK (BAY CITY), Matagorda	Maria Cummins	Skelly	Reflection	1934										M		86,844	Frio	8708	
WEST COLUMBIA, Brazoria	J.E. Bell	Miscellaneous	Mound, gas seeps & paraffin dirt	1902*	650	750	10	x				T		P		78,600,000	Vicksburg	6306	
WITHERS, Wharton	J. Caldwell	Texas	Reflection	1935										M			Frio	7844	
RIO GRANDE VALLEY DOMES																			
GYP HILL, Brooks	Section 331	U.S. Gypsum Co.	Mound & outcrop of gypsum	1911			40	x									Miocene	4678	Gypsum mined
PALANGANA, Duval	Section 245 & 247	Miscellaneous	Surface geology	1916	350	985		x			T				T	3,631	Upper Saline Bayou	3180	(Producing salt brine. Abandoned (small sulphur mine, 250,000 tons (produced. Produced oil 1928-29 (only.
PIEDRAS PINTAS, Duval	Section 185 & 531	Miscellaneous	Oil & gas in water wells	1925	385†	1350					T				S	142,192	Upper Saline Bayou	4902	Produced oil 1925-26 and since 1934.

*Known long before 1901

†Presence of salt core at great depth. Known from torsion balance data, and at Cleveland from pendulum data.

P - Prolific production
M - Medium production
S - Small production
T - Trace of production

TABLE III

COASTAL LOUISIANA SALT DOMES

FIELD AND PARISH	SURVEY	CURRENTLY CONTROLLING COMPANIES	INDICATIONS LEADING TO DISCOVERY	YEAR OF DISCOVERY (Proof of structure or discovery of oil or gas)	TO SHALLOWEST DRILLED DEPTH IN FEET BELOW SURFACE		TOPOGRAPHIC EXPRESSION		SITUATION		PRODUCING HORIZON					PRODUCTION THROUGH 1935 IN BARRELS	DEEPEST WELL DRILLED TO END OF 1935		REMARKS
					CAP ROCK	SALT CORE	HEIGHT OF MOUND IN FEET	CENTRAL DEPRESSION	IN MARSH	IN LAKE OR BAY	CAP ROCK	PLIOCENE	MIOCENE	OLIGOCENE	EOCENE		FORMATION	DEPTH OF HOLE IN FEET	
ANSE LA BUTTE, St. Martin	T9S, R5E	Miscellaneous	Mound, gas seeps & paraffin dirt	1902*	no	160	9	x				M	S			809,106	Miocene	6219	In salt, Salt brine produced
AVERY ISLAND, Iberia	T13S, R5 & 6E	International Salt Co.	Mound	1901*	no	10	120	x									Miocene	5873	Salt mine operating
BAYOU BLUE, Iberville	T9S, R10 & 11E	Humble	Refraction	1926	2792	2802			x				S			69,968	Miocene	6103	Produced oil 1929-31 only.
BAYOU BOUILLON, St. Martin	T9S, R8 & 9E	Miscellaneous	Gas seeps & paraffin dirt	1901	1260	1609			x				S			472,751	Vicksburg	6471	Produced oil 1926-31 only
BAYOU DE GLAISE, Iberville	T8S, R8E	Humble	Refraction	1927	3478	3697			x								Miocene	4285	In salt
BAYOU MALLET, Acadia	T7S, R1E	Woodley & Superior	Reflection	1936										T			Oligocene	8337	Gas
BAY ST. ELAINE, Terrebonne	T22S, R18E	Texas	Refraction	1928	710	1463			x				S				Miocene	5600	
BELLE ISLE, St. Mary	T17 & 18S, R10E	Miscellaneous	Mound	1901*	350	100	60		x								Miocene	4125	Salt produced for a short time.
BIG LAKE, Cameron	T12S, R9W	Magnolia & Stanolind	Torsion balance & reflection	1935									M				Oligocene	9501	Gas
BLACK BAYOU, Cameron	T12S, R12W	Shell	Refraction & torsion balance	1927	881	1709			x				P	S		2,000,000	Oligocene	6985	
BOSCO, Acadia	T8S, R3E	Superior	Reflection	1933		†			x				S	P		7,000,000	Oligocene	10002	
CAILLOU ISLAND, Terrebonne	T23S, R20E	Texas	Refraction	1928	2741	3889			x				P			4,600,000	Miocene	5981	
CALCASIEU LAKE, Cameron	T13S, R9W	Miscellaneous	Refraction	1927	1446	2345				x							Miocene	6909	
CAMERON MEADOWS, Cameron	T14S, R13W	Miscellaneous	Gas seeps & refraction	1928	no	6179			x				M			1,600,000	Oligocene	9331	
CHACAHOULA, La Fourche	T15S, R15E	Miscellaneous	Refraction	1927	932	1261			x								Miocene	5190	
CHENEYVILLE, Rapides	T1S, R2E	Amerada	Reflection	1935											S	6,451	Upper Saline Bayou	6777	
CHOCTAW, Iberville	T9S, R11E	Gulf & Standard of La.	Refraction	1927	417	656			x	x			M			933,289	Frio	6890	Salt brine produced
COTE BLANCHE, St. Mary	T15S, R7E	Miscellaneous	Mound	1901*	no	298	100		x	x							Miocene	2836	
DARROW, Ascension	T10S, R2E	Humble	Oil in water wells & torsion balance	1928	4798	4627							M			276,162	Miocene	6646	One well in Oligocene
DOG LAKE, Terrebonne	T21 & 22S, R16E	Texas	Refraction	1927	1439	1730				x		S	S			7,273	Miocene	7128	Produced oil 1929-30 only.
EAST BAY JUNOP, Terrebonne	T21S, R14E	Texas	Refraction	1927	4247	6468				x							Miocene	7070	In salt
EAST HACKBERRY, Cameron	T12S, R9 & 10W	Miscellaneous	Refraction	1926	2934	3300			x	x		T	P	P		12,600,000	Oligocene	8334	
EDGERLY, Calcasieu	T9S, R11W	Miscellaneous	Gas seeps & paraffin dirt	1906	3958	3991					T	T	P			8,000,000	Vicksburg	8414	
FAUSSE POINT, Iberia	T11S, R8E	Texas & Sun	Refraction	1926	798	823			x	x	T	T				5,181	Miocene	6307	Produced oil 1927-28 only
FOUR ISLE, Terrebonne	T21S, R16E	Texas	Refraction	1926	496	1307			x	x			M			240,906	Miocene	6923	Produced oil since 1934
GARDEN ISLAND BAY, Plaquemines	T23S, R32 & 33E	Texas	Refraction	1928	1691	2017			x	x		S	P			105,624	Miocene	5618	Produced oil since 1935
GILLIS (ENGLISH BAYOU), Calcasieu	T9S, R8W	Miscellaneous	Refraction	1934									S	P		2,000,000	Oligocene	8125	
GUEYDAN, Vermillion	T11S, R1W	Pure	Refraction	1929	4458	5751							M			568,681	Oligocene	9545	Produced oil since 1932
HACKBERRY, Cameron	T12S, R10W	Miscellaneous	Mound, gas seeps & paraffin dirt	1902	1234	1967	23				T		M			2,000,000	Oligocene	7834	In salt, Salt brine produced
HOUMA, Terrebonne	T19S, R19E	Miscellaneous	Gas seeps & paraffin dirt	1911									S				Miocene	5645	Gas
IOWA, Calcasieu & Jefferson Davis	T9S, R6 & 7W	Shell & Magnolia	Refraction & torsion balance	1929		†							M	P		16,000,000	Oligocene	7590	

TABLE III (*Continued*)

JEANERETTE, St. Mary	T13S, R9E	Norton Oil Co.	Paraffin dirt & reflection	1935										T	T		Miocene	8000	
JEFFERSON ISLAND, Iberia	T12S, R5E	Jefferson Lake Oil Co. & Jefferson Salt Co.	Mound	1901*	554 No cap on peak	78	70	x		x							Oligocene	8446	Salt and sulphur mined
JENNINGS (EVANGELINE), Acadia	T9S, R2W	Miscellaneous	Gas seeps & paraffin dirt	1901*	2000	3716	8	x					P	M		51,500,000	Oligocene	8903	
LA FITTE (BAYOU ST.DENIS), Jefferson	T17S, R24E	Texas	Reflection	1935					x				M			516,526	Miocene	9635	
LA ROSE (VALENTINE), La Fourche	T17S, R20E	Barnsdall & Gulf	Reflection	1933	no	6850											Oligocene	7216	
LAKE BARRE, Terrebonne	T21S, R19 & 20E	Texas	Refraction	1928	741	852			x	x		T	P			12,000,000	Miocene	7162	Overhang production
LAKE HERMITAGE, Plaquemines	T18S, R25E	Gulf & Humble	Refraction	1933	905	3814			x	x			S			71,506	Miocene	6472	
LAKE MONGOULOIS, St. Martin	T10S, R9E	Texas	Gas seeps & reflection	1936	no	7540			x	x							Miocene	7584	In salt
LAKE PELTO, Terrebonne	T23S, R18E	Texas	Refraction	1928	1810	2232				x		T	M			278,463	Miocene	7298	
LAKE WASHINGTON, Plaquemines	T20S, R26E	Humble, Gulf, Shell & Freeport Sulphur	Gas seeps & refraction	1930	1070	1545			x	x	P	S				1,000,000	Miocene	5681	Sulphur produced
LEEVILLE, La Fourche	T21S, R22E	Texas & Gulf	Refraction	1930	3789	3896			x			T	P			9,600,000	Miocene	7300	In salt
LOCKPORT, Calcasieu	T10S, R9W	Magnolia & Gulf	Gas seeps	1924		†			x				P	M		13,000,000	Oligocene	7902	
NAPOLEONVILLE, Assumption	T12S, R13E	Miscellaneous	Refraction	1926	413	685											Miocene	6037	
NEW IBERIA, Iberia	T12S, R7E	Miscellaneous	Gas seeps & paraffin dirt	1917	1600 No cap on peak	805					T	S	S			693,538	Oligocene	7934	
PINE PRAIRIE, Evangeline	T3S, R1W	Miscellaneous	Cap rock & oil show	1908	On surface	516	20	x						S		20,000	Oligocene	5112	Produced oil 1912-18 only
PORT BARRE, St. Landry	T6S, R5E	Texas, Gulf & Pan American	Refraction	1928	3551	3642			x				S	M		5,000,000	Oligocene	4909	
ROANOKE, Jefferson Davis	T9S, R4W	Shell & Humble	Torsion balance	1925		†							M	P		1,800,000	Oligocene	10750	
ST.MARTINVILLE, St. Martin	T11S, R6E	Tide Water	Gas seeps, paraffin dirt, refraction & reflection	1935		†							M			17,875	Miocene	5582	A perennial prospect for past 15 years on basis of gas seeps and paraffin dirt. ? Shades drilling at 8340 feet 2-12-36
SECTION "28", St. Martin	T9S, R7E	Miscellaneous	Gas seeps & paraffin dirt	1917	1030	1189			x								Miocene	6761	
SORRENTO, Ascension	T10S, R4E	Athens Oil Co.	Mound, gas in water well, refraction & torsion balance	1926	1568	1980	8		x		M			M		650,898	Vicksburg	6630	Drilled before 1922 on basis of surface indications. In salt
STARKS, Calcasieu	T9S, R12W	Gulf & Standard of La.	Refraction	1925	1202	2015					T	T	M	T		2,000,000	Vicksburg	7807	
SULPHUR, Calcasieu	T9S, R10W	Union Sulphur	Mound & oil seeps	1901*	350	1460	8	x	x	x	T		P	T		6,000,000	Oligocene	9250	In salt. (Formerly rich sulphur mine, ten million tons reported produced. Now abandoned)
SWEET LAKE, Cameron	T13S, R8W	Pure	Gas seeps	1926						x			P			3,000,000	Miocene	8070	
TEPETATE, Acadia	T7S, R2W	Continental	Torsion balance & reflection	1935		†								P		126,881	Oligocene	9000	
VENICE, Plaquemines	T21S, R30E	Gulf, Humble & Simms	Gas seeps & refraction	1928	1535	2340			x								Pliocene	3500	
VERMILION BAY, Iberia	T16S, R5E	W. T. Burton	Refraction	1927	787	796				x							Miocene	6528	
VINTON, Calcasieu	T10 & 11S, R12W	Miscellaneous	Mound, oil in water wells & sour water	1902*	364	985	27	x			T	T	P	S		41,000,000	Vicksburg	6553	
WEEKS ISLAND, Iberia	T14S, R6 & 7E	Miscellaneous	Mound	1901*		100	120	x	x								?	917	Salt mined
WELSH, Jefferson Davis	T9S, R5W	Stanolind, Humble & Tide Water	Gas seeps	1901		†						S				585,069	Vicksburg	6107	
WHITE CASTLE, Iberville	T11S, R12E	Shell	Refraction	1926	1693	2313			x				P	S		1,400,000	Miocene	6942	

*Known long before 1901

† Presence of salt core at great depth known from torsion balance data.

P – Prolific production
M – Medium production
S – Small production
T – Trace of production

Thirty-three domes have surface mounds and thirteen of these have central basins.

CAP ROCK AND SALT

Cap rock has been penetrated in forty-three Texas salt domes and thirty-nine Louisiana domes. Two of these have no cap rock in the peak of the dome. On two domes (Pine Island and Gyp Hill), cap rock is exposed at the surface. Salt has been penetrated in forty-seven Texas domes and forty-six domes in Louisiana. The presence of the salt on twenty-six other domes is indicated by the data of gravitational surveys. Depth to salt or cap rock is recapitulated herewith.

Cap Rock or Salt Penetrated (Depth in Feet)	*Texas*	*Louisiana*	*Total*
Less than 500	13	12	25
500–1,000	17	8	25
1,000–1,500	5	7	12
1,500–2,000	1	6	7
2,000–3,000	1	3	4
3,000–4,000	5	4	9
4,000–5,000	1	3	4
5,000–6,000	1		1
6,000–7,000		2	2
7,000–8,000	3	1	4
No cap or salt	33	15	48

PRODUCTION

Through 1935 the coastal salt-dome oil fields of Texas and Louisiana have produced 1,154,141,932 barrels of oil. Of this, 942,586,244 barrels were produced in Texas, and 211,555,688 barrels in Louisiana. Ninety-three domes are now producing oil. Ten are producing gas and distillate. Ten domes formerly producing have ceased to produce. On four domes oil is being produced from overhanging salt or cap rock. Six domes are producing sulphur, and three are exhausted as sulphur producers. Rock salt is being mined from four domes, brine is being produced from four, and gypsum is being quarried on one dome. Below is shown the number of domes which have produced even a small quantity of oil from the several horizons.

Producing Horizon	*Texas*	*Louisiana*	*Total*
Cap rock	20	9	29
Pliocene	15	14	29
Miocene	39	38	77
Oligocene	47	18	65
Eocene	24	1	25

DEEP WELLS

The average depth to which the deepest well was drilled on each dome is 6,820 feet. The abandonment horizon totals for these deepest wells are shown herewith.

Formation to Which Deepest Well Drilled	*Texas*	*Louisiana*	*Total*
Pliocene		1	1
Miocene	7	31	38
Oligocene	8	20	28
Frio	10	1	11
Vicksburg	17	6	23
Jackson	4		4
Whitsett	1		1
McElroy	4		4
Caddell	1		1
Cockfield	2		2
Upper Saline Bayou	12	1	13
Lower Saline Bayou	8		8
Sparta	3		3
Wilcox	3		3
Unclassified		1	1

Tables II and III contain the assembled data on each coastal dome.

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CONROE OIL FIELD, MONTGOMERY COUNTY, TEXAS[1]

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ABSTRACT

The Conroe oil field, located in Montgomery County, Texas, was discovered in 1931. It is a broad ovate structure crossed by several normal faults which form a central graben area. The maximum vertical displacements of these faults range from 130 to 165 feet. Production is obtained at an average depth of 5,050 feet from the Cockfield formation of Upper Claiborne (Eocene) age, which has been uplifted more than 800 feet above its normal position. The average thickness of the Conroe producing sand throughout the field is 60 feet. The recoverable reserves have been estimated to be about 600 million barrels. Currently the field is producing daily 47,700 barrels of oil from 829 wells, of which 53 wells are producing salt water in varying amounts.

There is free communication and equalization of fluid across the fault planes so that there exists a unit reservoir wherein the fluids segregate themselves at uniform levels throughout the field. The interval within which sand may contain oil is 130 feet, or between the −4,860-foot and −4,990-foot datum planes. A large gas cap overlies the oil and occupies an interval of 170 feet, or between the datum planes of −4,690 and −4,860 feet. Conroe has a proved area of 17,200 acres and has produced a little more than 40 million barrels of oil up to January 1, 1935. Reservoir pressures became stabilized after the field has produced about 29 million barrels of oil and the pressure decline since then has been less than one pound per million barrels of oil produced.

INTRODUCTION

The discovery of the Conroe structure and its attendant oil field definitely proved a new Gulf Coast era. It is true that Goose Creek and Orange were early forerunners of the type of deep-seated oil field structures; that Raccoon Bend and Thompsons later paved the way for Conroe and dozens of similar structures, which now dominate the Gulf Coast oil industry. The discovery of Conroe marked the definite passage from the so-called "piercement" type field domes to those whose motivating force was very deeply seated. Whatever the source of this energy, it produced the broadly arched faulted Conroe dome.

The discovery of the Conroe structure was also of great importance because of the great size of the accompanying oil field. Its 17,200 productive acres exceeded the total of the entire producing areas of the oil fields existing at that time in the entire salt-dome area of the Gulf Coast of Texas and Louisiana. This discovery also encouraged numer-

[1] Manuscript received, March 30, 1936.

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ous operators to come to the Gulf Coast area from other regions in an effort to add to their dwindling oil supplies. These and other operators inaugurated a campaign of wildcatting along the general geologic strike position of the Conroe field in a futile effort to find similar prolific structures. Prior to Conroe only Pettus had produced appreciable quantities of oil from the Cockfield formation from which Conroe is producing, so that Conroe established the Cockfield as a prolific possibility in the salt-dome area of the Coast.

Conroe, with its broadly arched dome, crossed by numerous faults, which form a central graben, is almost identical with the type Raccoon Bend structure, as well as identical in general character with numerous structures discovered later, such as Tomball, Livingston, Hastings, Cleveland, and many others. The faults of Conroe, as well as being interesting geologic phenomena, have permitted fluid equilibrium throughout the reservoir, because they have placed in juxtaposition, and therefore in communication, several sands that occupy different stratigraphic levels in the Cockfield section.

ACKNOWLEDGMENTS

The writers are indebted to the Humble Oil and Refining Company and the Conroe Operators Association for extending permission for the publication of this study. They are grateful to L. P. Teas and Donald C. Barton for helpful suggestions and criticism and editing the manuscript. Appreciation is expressed to T. V. Moore for constructive comments on the reservoir conditions of the field; and to the field engineers of the Humble, Tide Water, Sun, Texas, and Amerada companies, who have contributed greatly in making bottom-hole pressure surveys at Conroe.

LOCATION

The Conroe oil field is located along the northern boundary of the salt dome province of Gulf Coastal Texas (Fig. 1). It is in south-central Montgomery County, 5 miles southeast of Conroe, the county seat, and 40 miles north of Houston. The Humble field is 20 miles southeast and Tomball is 17 miles southwest. Pettus, the first major Cockfield oil producing area, lies approximately 170 miles southwestward. The Gulf, Colorado and Santa Fe Railroad is located 1½ miles north, while the International and Great Northern Railroad lies 3 miles west. A paved highway connects Houston and Conroe, and improved and gravel roads make all parts of the field easily accessible.

HISTORY

The site of the Conroe field, after gas seeps had been found on the Rhodes farm in the W. S. Rhodes Survey, had attracted the attention

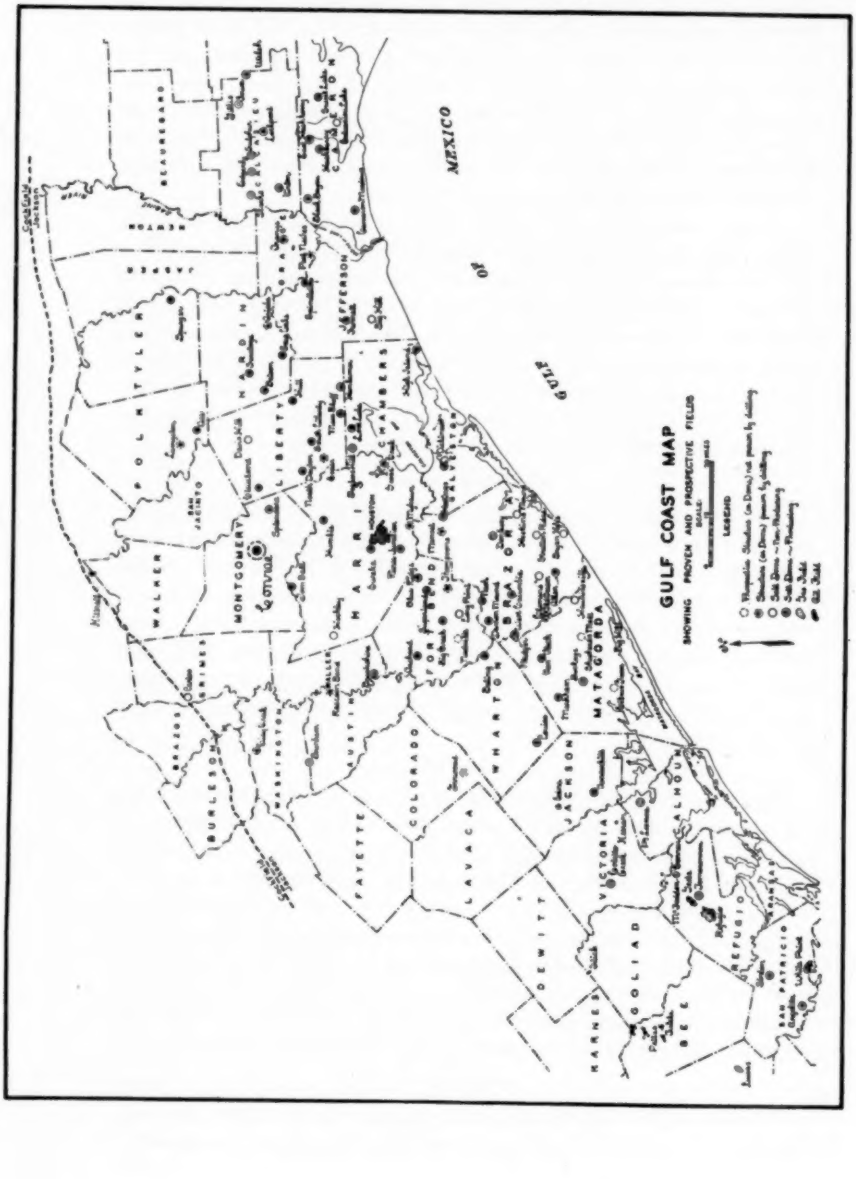

FIG. 1.—Map showing location of Conroe oil field.

of a group of local men, who formed the Crystal Creek Oil Company in 1919. A block of 5,000 acres was assembled in and around the Ransom House Survey, now the center of the oil field, but this acreage was surrendered when development could not be obtained.

Later, and prior to the discovery of oil, several shallow tests had been drilled in the Conroe area, but all were abandoned without revealing any indications of structure. Incomplete and questionable records show that as far back as 1924 El Saline Petroleum Company's Outlaw No. 1, situated in the G. W. Wagers Survey, which later proved to be at the southeast extremity of the field, found gas in noticeable quantities before it was abandoned at 1,961 feet.

With the advent of geophysics, the area was considered to be of more than casual interest because of its proximity to a postulated torsion-balance "minimum ridge." However, peculiar clay exposures in the Josh Smith and J. Toops surveys, noted in 1927, and interpreted by many geologists to be Lagarto inliers, led to the acquisition of leases by several major oil companies. Five of these concerns blocked acreage for geophysical exploration, and after extending their surveys sufficiently southward to have included three-fourths of the area that later produced, each in succession turned back the leases. Refraction-seismograph and torsion-balance methods were used, but apparently with no conclusive proof of any impressive anomaly. Nevertheless, two vague gravity minima did exist, located respectively on the north and south flanks. Some acreage was retained on this evidence by the Humble and Gulf companies.

Deep drilling in the Conroe region actually began in 1929 with Kelly-Baker's M. Juergens No. 1, located in the D. James Survey, 2 miles west of the town of Conroe. This test was "junked" at 3,662 feet and a second well was commenced in the same locality in February, 1932. A gas showing was reported to have been found from 4,680 to 4,685 feet, and an oil showing was logged from 4,700 to 4,725 feet. After the discovery of Conroe, this well was carried to the Cockfield, where it proved a failure.

In 1930, George W. Strake, an independent operator, became interested and assembled about 9,300 acres, lying 6½ miles southeast of Conroe, which now includes the west and northwest portions of the oil field. Acreage comprising this block was a part of that held with shooting privileges by various companies and subsequently released. Due mainly to this fact, Strake was unable to obtain financial assistance from outside sources to begin his test well, the South Texas Development Company's No. 1, approximately 1,300 feet south of the present northwest limits of the field, in the Theo. Slade Survey.

The well was started on August 30, 1931. After the usual delays experienced in wildcat development, a gas sand having an oil stain was found at 4,991 feet. Very little attention was paid to this showing and it was necessary to trade some of the acreage for a string of 7-inch casing. The well was completed on December 13, 1931, and sprayed some condensate with 15 million cubic feet of gas daily through a ⅝-inch choke. The producing horizon was established as a member of the Cockfield formation of Claiborne age, but as little was known of the productivity of this formation, trading on adjoining tracts was slow and the considerations nominal. The Strake Petroleum Corporation's South Texas Development Company No. 2, 2,400 feet south of the initial test, should probably be regarded as the discovery well, as it was the first to penetrate the main Conroe sand horizon and produce oil commercially. Casing was set after 270 feet of Cockfield penetration, when approximately 20 feet of oil-saturated sand was found. It was completed June 5, 1932, at a depth of 5,026 feet and flowed 900 barrels of oil daily through a ½-inch choke.

The Heep Oil Corporation's (Tide Water Oil Company's) Freeman No. 1 was completed 5 days later, extending the field 2 miles northeast.

PHYSIOGRAPHY

The Conroe field is crossed at the north end by an east-west trending belt of low, rather indistinct hills, which separates the area into two physiographic phases. Northward the relief is gently rolling and the soil consists of the Hockley soil series.[4] The southern phase is an almost expressionless wooded plain, locally known as "flatwoods." The Katy and Acadia soil series[5] occupy that flat land, which slopes coastward at the rate of 4 feet per mile. This is in marked contrast with the more pronounced slope of 15 feet per mile of the northern phase. The hills may be seen best in the vicinity of the Harrison-Abercrombie's Alexander No. 1 blow-out crater. The average altitude in the upland area is 210 feet, and that of the bounding "flatwoods" lowland is 145 feet.

The west fork of San Jacinto River, a mature coastal plain trunk stream, lies west of the oil field and approaches within a mile of production at the confluence with youthful Crystal Creek. Divided into three branches which coalesce in the Wilson Strickland Survey, Crystal Creek drains the northwest half of the uplands area, setting up a

[4] H. V. Geib and T. M. Bushnell, "United States Soil Survey" Katy, p. 1930, Hockley, p. 1933, Acadia, p. 1936.

[5] H. V. Geib and T. M. Bushnell, *op. cit.*

typical dendritic drainage pattern.[6] In contrast with that system is the ineffectively drained, low-lying terrain on the south and southeast, where numerous large, shallow, consequent ponds, averaging 4 acres in area, are conspicuous.

The area is densely wooded with typical East Texas short-leaf pine, interrupted only by a few cleared, poor, sandy-soil farms and the usual 4-acre well-site clearings. In the lowland, as well as in the San Jacinto River valley, there is a mixture of hardwood timber. The mean annual rainfall and temperature are 48.28 inches and 67.9°F., respectively; consequently, the territory is subject to normal sub-humid processes of erosion.

STRATIGRAPHY

SURFACE FORMATIONS

The surface is covered by the normal outcrop of the Lissie and Reynosa formations, made of red, yellow, and gray sands and some gravel.

Brown and gray mottled clays questionably identified as Lagarto are exposed along San Jacinto River near the western boundary of the Lemuel Smith Survey, 1 mile southwest of the producing limits. Similar clay deposits exist near Beach, 2 miles north of the field. They have been discovered in the Wilson Strickland Survey, and extend eastward across Montgomery County.

SUBSURFACE FORMATIONS

Lissie-Reynosa formations (*Pleistocene*).—From the surface to approximately 125 feet, very loose, unconsolidated, red, iron-stained and cross-bedded sand and gravel and vari-colored sandy clay lenses persist.

Lagarto-Oakville formations (*Miocene and Pliocene*).—The Lagarto-Oakville formation is composed of greenish gray, tan and some reddish brown clays with small lime nodules, or concretions, together with fine to medium-textured sandstones. An abundance of redeposited Cretaceous *Foraminifera* and *Inoceramus* prisms is found well preserved in the clays, while the sands carry many fragments of reworked Cretaceous megascopic forms.

This section is 1,400 feet thick and is not subdivided here into the Lagarto and Oakville formations, but is assigned to a single unit because of their sameness in lithologic character. It is true, however, that the clays became sandier and that there is a greater abundance of sand encountered as depth is attained.

[6] Emilie R. Zernitz, *Jour. of Geol.*, Vol. 40 (1932), p. 499.

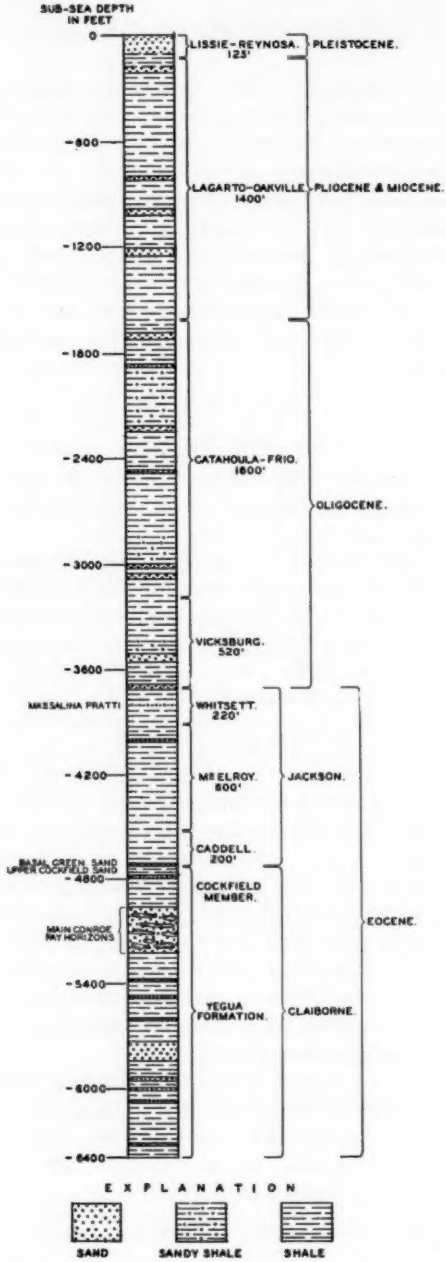

FIG. 2.—Generalized stratigraphic section encountered in Conroe field. Catahoula-Frio section is here tentatively assigned to Oligocene, but in part may belong to Miocene.

Catahoula-Frio formations (*Oligocene*).—Olive-green, non-calcareous, ashy clays with imbedded lime nodules and particles of volcanic glass and traces of free lignite, and a series of beds with coarse sands ("rice" sands) composed of quartz and chert at the base, represent the Catahoula-Frio section at Conroe. The usual thickness is 1,600 feet.

Few fossils are found in this formation with exception of a zone of Ostrea which is normally encountered after 250 feet penetration. Lithologically, the lower 200 feet of the section reveals but a slight change, although the lowermost clays became less ashy and an increase in free lignite is apparent immediately above and below the coarse-grained sands.

Vicksburg formation (*Lower Oligocene*).—The Vicksburg formation, with its carbonaceous brown to black shales, is in decided lithologic contrast with the overlying ashy olive-green clays and gray coarse sands of the Catahoula-Frio section.

A zone of arenaceous *Foraminifera*, *Haplophragmoides* and *Ammobaculites*, found 100 feet down in the Vicksburg formation, affords an identifiable horizon, which in turn is followed 300 feet below by a more diagnostic foraminifer, *Textularia warreni*. That fossil, with *Textularia mississippiensis* and a few other non-diagnostic *Foraminifera*, complete the faunal assemblage of the lower Vicksburg.

Shales predominate throughout the 520 feet occupied by this formation, although several thick bodies of fine to medium-grained argillaceous sands occur near its base.

Whitsett formation (*Jackson series. Eocene*).—Ranging from 200 to 220 feet in thickness, the Whitsett formation underlies the Vicksburg. That formation consists of brittle, laminated, dark gray to brown and black fossiliferous marine shales. Unlike the Whitsett at Raccoon Bend, sand is present only in meager quantities, being found only in the *Massalina pratti* fossil zone in the middle of the formation and again in a thin stratum near the contact of the underlying McElroy formation.

McElroy formation (*Jackson Eocene*).—The McElroy formation, because of a distinctive foraminifer, *Textularia hockleyensis*, is one of the most reliable key beds in the entire section encountered at Conroe. Dark gray to black brittle shales with traces of coarse-textured sand, associated with some siderite near the base, comprise the McElroy. The average thickness is 600 feet.

Caddell formation (*Jackson Eocene*).—The Caddell formation is at the base of the Jackson series and occupies a 200-foot interval between the McElroy and Cockfield formations. Dark gray brittle

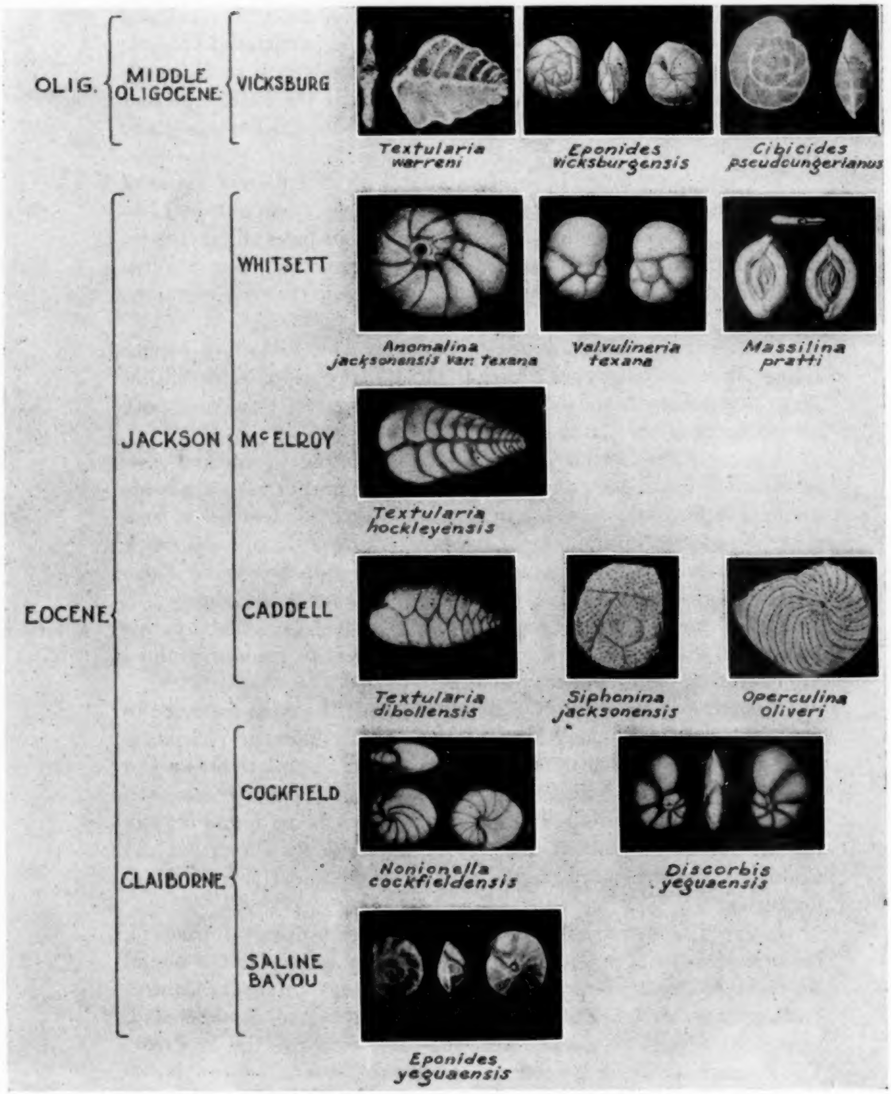

FIG. 3.—Index *Foraminifera* used in determining formations in Conroe field.

shales, grading into a grayish green, become more fossiliferous as the percentage of glauconite increases throughout the lower half of this formation. Thirty feet from its base there is a green-sand marl with spots of clean glauconite. This highly fossiliferous bed has a wealth of large, well preserved Eocene gastropods and pelecepods with an abundance of *Foraminifera*, the most important of which is *Operculina oliveri*.

Yegua formation—Cockfield member (*Claiborne series. Eocene*).—Chocolate brown, laminated, brittle shale, containing some interspersed lignite fragments, leaf imprints, and siderite, compose the Cockfield formation, which is decidedly dissimilar to the basal glauconitic Caddell above it. Shales and sandy shales enclosing the two important producing sand horizons comprise the section.

Upper Saline Bayou member (*Claiborne Eocene*).—The upper Saline Bayou lies immediately beneath the Cockfield, but on account of the paucity of diagnostic upper Saline Bayou fossils and the similarity of the sands occurring in both formations, it is difficult to differentiate the two formations.

Located on the extreme south flank of the field, the Sun Oil Company's Foster No. 11, John Bricker Survey, was abandoned at 1,400 feet in the Claiborne, after having passed through the entire Cockfield section and penetrated far into the upper Saline Bayou without finding oil. It is interesting that 500 feet of sand occurred within the Claiborne series, and also that a coarse-textured porous sand body 100 feet thick was logged 300 feet beneath the Conroe sand horizon, or approximately 800 feet below the top of the Cockfield formation.

STRUCTURE

SURFACE

Surface expression of structure has not been definitely proved; yet clay deposits different in color and texture from the encircling red sands and sandy clays of Lissie-Reynosa age have been interpreted by some to represent Lagarto inliers. Subsequent drilling, however, has demonstrated many similar clay exposures to be normal and without definite structural significance.

Most striking are the indirect indications of geologic structure intimated by hydrogen-sulphide springs in rivulets and shallow water wells containing an unusually high concentration of total solids, as well as an unverified report[7] of gas seepages associated with significant clay outcrops in the Ransom House and Wilson Strickland surveys in the middle of the field.

[7] George Bevier, personal communication.

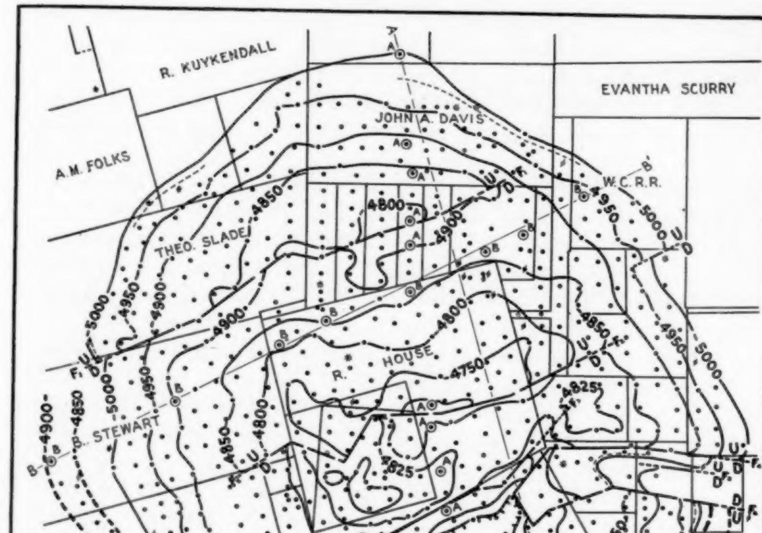

FIG. 4.—Geologic structure map contoured on top of Conroe sand, Conroe field.

The forrested terrain was an obstacle to surface work which may have led to evidence of structure, yet the writers believe that through a detailed study of the stratigraphy, surface structural relief at Conroe will become apparent.

SUBSURFACE

The subsurface structure consists of a slightly elongated dome with the major axis trending northwest and southeast (Fig. 4). Minor faulting on the flanks has caused irregularities which have resulted in numerous re-entrants that modify the symmetrical ovate pattern. Structural uplift on the Cockfield is in excess of 800 feet and all overlying formations as high as the Catahoula definitely reflect an uplift.

TABLE I

STRUCTURAL CLOSURE ON FORMATIONS IN THE CONROE FIELD

Formation	*Feet*
Catahoula	100 approx.
Vicksburg	150–200
Whitsett	200–250
McElroy	250–300
Caddell	250–300
Cockfield	300–360

Uplift of formations younger than Catahoula, the writers assume, is also present, but contacts of these formations have not been determined by coring to a sufficient accuracy to substantiate this view.

The oil and gas closure, excluding the upper Cockfield sand horizon, amounts to 300 feet, although the structural closure is 360 feet. Gas occupies a zone or interval of 170 feet and the oil zone is 130 feet in thickness. The highest well drilled in the field is the Humble Oil and Refining Company's Dobbin No. 3, Ransom House Survey, which found the Cockfield formation at −4,480 feet and encountered the Conroe sand at −4,690 feet.

Structural thinning of formations over the dome is perceptible to a small degree in the easily recognizable formations of the Jackson series. Arching of sediments by a long sustained vigorous, intrusive force continued contemporaneously with the deposition of the sediments, and the entire Jackson series, which normally is 1,150 feet thick, is known to have a minimum thickness of 1,030 feet near the apex of the structure.

The Conroe structure in a north-south direction (Fig. 5) extends from the Houston Oil Company's Brent No. 1, located in the D. W. Collins Survey, to Plummer and McDaniels' Keystone Mills No. 1, approximately 7 miles south, in the Ashby James Survey. The dip of

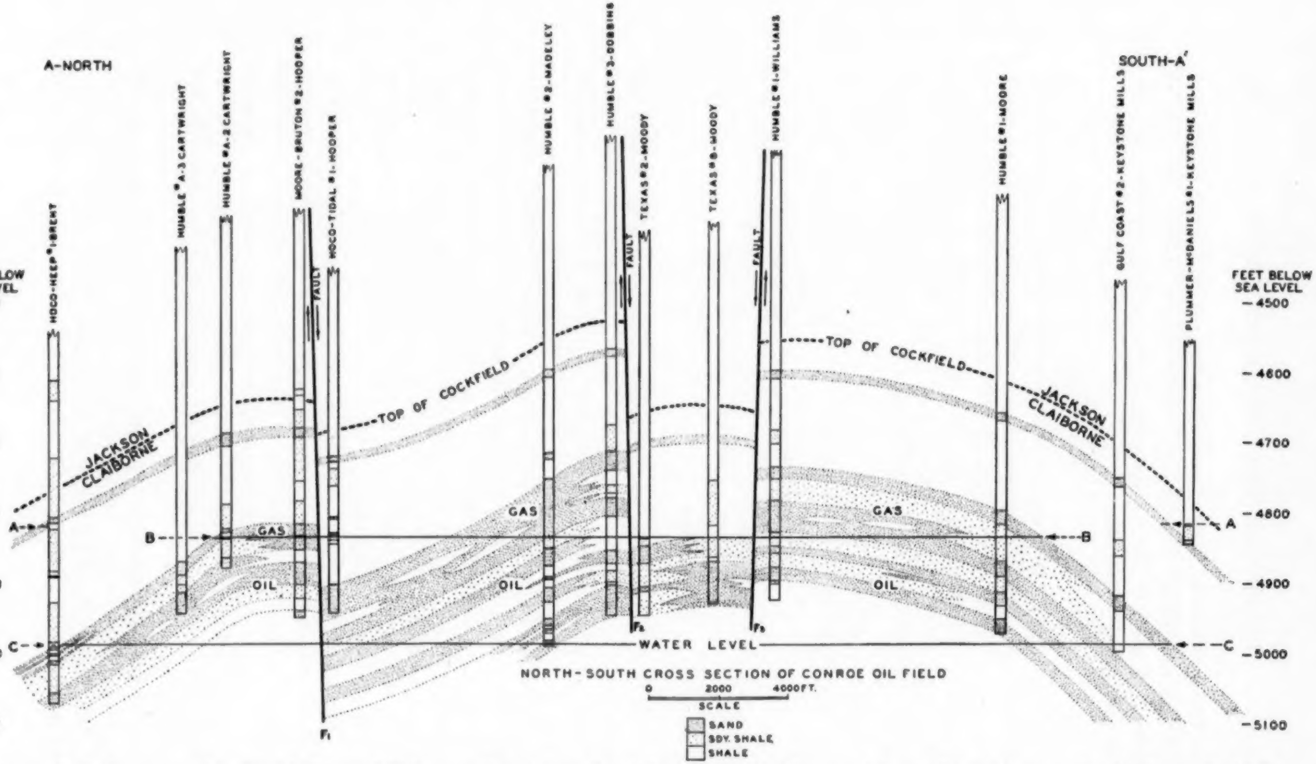

FIG. 5.—Geologic cross section through Conroe field from northwest to southeast along line *AA'* in Figure 4. *AA*, gas-oil contact at −4,850 feet, upper Cockfield sand; *BB*, gas-oil contact at −4,860 feet, Conroe sand; *CC*, water level at −4,990 feet.

TABLE II
STRUCTURAL THINNING
(JACKSON SERIES)

Formation	*Normal Thickness (Feet)*	*Minimum Thickness (Feet)*	*Per Cent Thinned*
Whitsett	250	220	12
McElroy	660	600	9
Caddell	240	210	13
Total Jackson series	1,150	1,030	11

the structure to the north is in contrast with its steeply dipping southern border which, from the Humble Oil and Refining Company's Moore No. 1, to the Keystone Mills No. 1 well attains an average dip of 115 feet per mile. A central graben area crosses the structural apex. It is caused by normal faults which traverse the structure northeast and southwest. Faulting may have affected also younger beds than the Catahoula, but it can not be recognized because of the lithologic similarity of the younger beds, which tends to obliterate evidence of faulting.

The structure in a west-east direction (Fig. 6) extends from the Strake Petroleum Company's Schaefer No. 1 to the Humble Oil and Refining Company's Emory No. 2, and represents that portion of the structure lying between and paralleling faults F1 and F2 (Figs. 4 and 5). Formation dips on both the west and east sides of the structure are approximately the same, and drag folding is prominent in the area of the Humble Oil and Refining Company's Madeley No. 6 and Alexander No. 2. The depressed central portion of the dome is 1½ miles in length and occurs between the Humble Oil and Refining Company's Madeley No. 3 and Abercrombie-Harrison's Alexander No. 2.

FAULTS

The regularity of the dome at Conroe has been broken by three major faults. They have an average hade of 51° and trend N. 82° E. across the field. These faults as well as several minor peripheral faults are indicated by a marked decrease in the thickness of the various Jackson formations, or by an abrupt difference in the depth to the Cockfield formation in offset wells.

The northernmost fault, F1 (Fig. 4), begins in the western part of the Theo. Slade survey and continues to the southwest corner of the John Davis Survey. The upthrow of this fault is to the north and the downthrow is to the south. In the vicinity of Moore and Bruton's Hooper No. 2, its maximum displacement is 130 feet.

The central faults, F2 and F3, roughly parallel the trend of fault

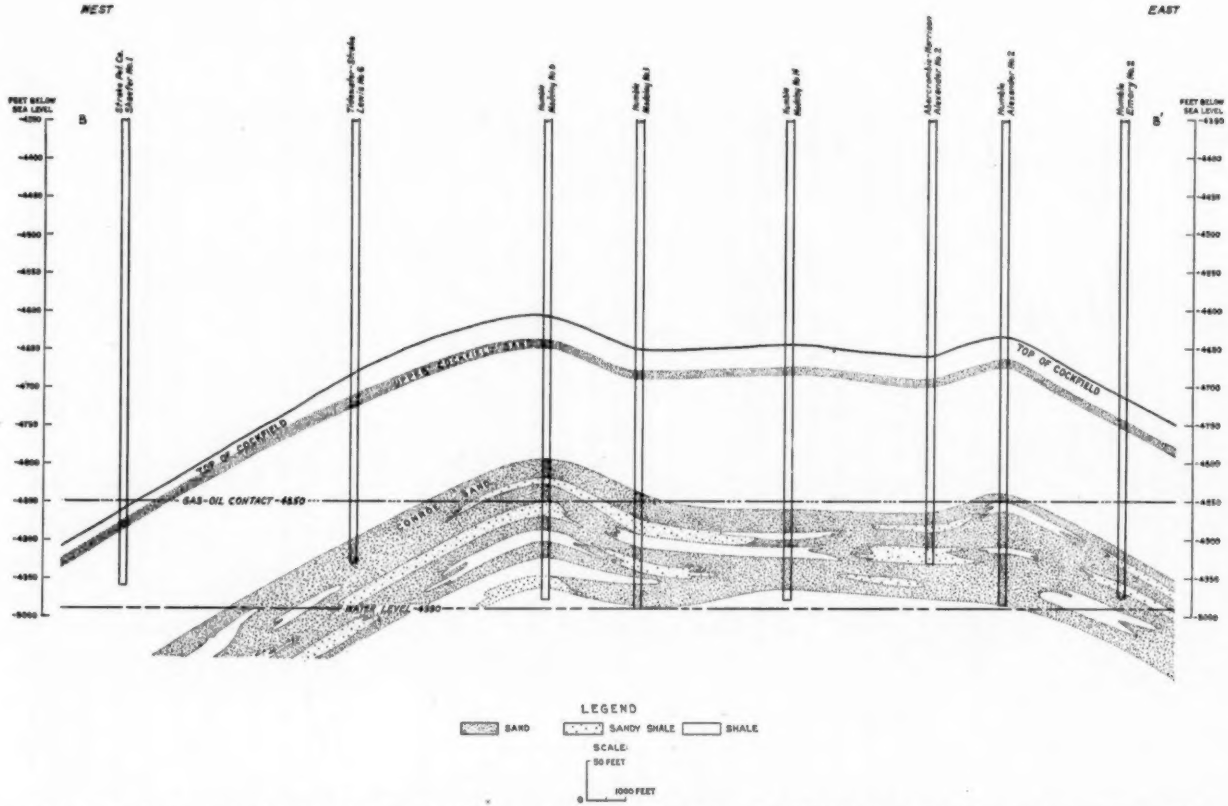

FIG. 6.—Geologic cross section through Conroe field from southwest to northeast along line BB' in Figure 4. Faulting does not appear on this cross section because portion of structure shown parallels and lies between faults F_1 and F_2 in Figures 4 and 5.

F1 and lie near the center of the field extending eastward from the west line of the Ransom House and Wilson Strickland surveys to the C. A. West and T. & N. O. R. R. surveys. The two latter faults compensate one another and were possibly formed simultaneously during the primary stage of fault development on the structure. F2 has its downthrow to the south and a maximum displacement of approximately 165 feet, while F3 is downthrown to the north, and has nearly the same maximum displacement. Faults F2 and F3 create, therefore, a keystone graben,[8] ¾ mile in width, which occupies the exact central part of the dome and affords communication within it of the various sand horizons of the Cockfield section. Faults F2 and F3, like F1, attain their maximum displacements near the center of the uplift and they decrease, probably to zero, at the edge of the structure, where they are lost (Fig. 4).

A complex system of short tensional faults, 1 mile in length, is present in the territory of the T. M. Wiggins, J. M. Real and C. E. Manning surveys at the east border of the field. Faults F4, F5, and F6 form a wedge-like down-thrust block which continues eastward past the oil-producing outline. Fault F6, situated between the Humble Oil and Refining Company's Rooker No. 5 and the Sun Oil Company's Stewart No. 3, has a maximum throw of 274 feet, the greatest of any fault in the field.

The faults observed in the Conroe field are all normal; no reverse faults have been recognized.

PRODUCING SANDS

Oil and gas are obtained from one zone which occupies three horizons in the Cockfield formation. The first and third horizons are of greatest importance.

Upper Cockfield sand.—The first, or upper Cockfield horizon, encountered approximately 30 feet below the top of the Cockfield, is usually from 10 to 15 feet in thickness. This stratum is continuous across the field, but varies in shale content and porosity. Fine to medium-textured, sub-angular quartz grains associated with a few heavy minerals and a trace of mica are its predominant characteristics. The average porosity is 25 per cent.

The oil-producing area of the upper Cockfield sand forms a narrow semicircular belt, about 2,500 feet in width, around the south half of the structure, and includes 2,700 acres. In the extreme north part of the field, wells drilled into this horizon have encountered small showings of oil and an appreciable amount of gas. The westernmost

[8] Bailey and Robin Willis, *Geologic Structures*, pp. 80–81.

oil producers in this formation are the Strake Oil Company's Schaefer No. 1 and No. 2, C. B. Stewart Survey, located 2,000 feet west of their George Hamman No. 2, a well abandoned in the Conroe sand. The Humble Oil and Refining Company's South Texas Development Co. No. A-73, in the northwest corner of the Theo. Slade Survey, found the upper Cockfield sand at −4,866 feet and was drilled to −4,889 feet, but tested salt water and a small amount of oil. At the north edge of the field, the Houston Oil Company's Brent No. 1, located in the D. W. Collins Survey, was plugged back to −4,832 feet and completed as a gas well when salt water sand was cored at −4,992 feet in the Conroe horizon. The easternmost upper Cockfield producing well is the South Gulf Oil Company's Granger No. 2, T. & N. O. R. R. Survey No. 14.

Intermediate sand.—The Intermediate sand is a relatively unimportant producing horizon 100–130 feet below the Cockfield. Wells located high structurally log a poorly developed, gas-permeated sand, or its sandy shale counterpart, while toward the southeast, as the border of the dome is approached, the sand is reported to be as much as 30 feet thick and quite clean and porous. No attempt will be made in this paper to segregate the producing wells in this horizon from those completed in the deeper Conroe sand, since, to accomplish this, a detailed study is necessary and there are but meager data available.

(*Sand lens member*).—This is a zone composed of sand lenses which are not definitely a part of the Intermediate horizon and in some places is found 40 feet below it. These lenses are narrow stringers of fine-textured sand, never more than 15 feet thick, and are isolated from the reservoir by shale, except probably along the faults, where they are brought into contact with other horizons. Many of these sand lenses contain gas and high-gravity oil even where encountered at depths near the water level of the field.

Conroe sand.—The Conroe sand occurs throughout a 250-foot interval and is by far the most important producing horizon in the field. It consists primarily of sand and shaly sand which envelops the shale lenses.

This sand is found from 175 to 210 feet below the top of the Cockfield and is composed of fine to medium-textured quartz grains having a variable clay and shale content. There is no apparent contrast between the sands of this horizon and those of the Intermediate and upper Cockfield, but laboratory tests[9] indicate it to be a better reser-

[9] T. V. Moore, Humble Oil and Refining Company, personal communication.

voir, having an average porosity of 28 per cent and an average permeability of 263 millidarcys.

Since it is co-extensive with the entire uplifted area, the Conroe sand produces oil throughout the field within the limits of its −4,990-foot contour. Its area includes 14,500 productive acres.

TABLE III

	Number o Wells	*Average Oil Sand Thickness*
Upper Cockfield sand area	53	10 feet
Conroe sand area	776	60 feet
Total productive area	829	17,200 acres

RESERVOIR CONDITIONS

GAS-OIL LEVELS

The gas-oil level in the Conroe reservoir in general is between −4,850 and −4,860 feet. The contact does not lie exactly at one level, however, because deformational and depositional factors somewhat affect the levels the gas and oil assume in certain localities in the field. The character of the sand effects the level of the gas-oil contact. Loose, unconsolidated, coarse-textured sand in several places has been found practically without free gas when encountered as high as −4,835 feet. In the case of tight, indurated sand of low porosity and permeability, on the other hand, free gas is produced with high pressures at depths near water level even if the sand is heavily oil stained. This condition, however, is local and abnormal. Areas of highest porosity and permeability are developed away from the faults, whereas the indurated sands of lower porosity and permeability are directly associated with faults.

Three types of sand carry gas in the Conroe reservoir: 1, the dry gas sand which overlies the oil sand proper as a gas cap; 2, the indurated, cemented, slightly porous sand that may be found within the oil zone; and 3, the fine-textured silty sand which is also encountered within the zone occupied by oil. The third type seldom occurs with uniform thickness and is thought to belong to the sand lens horizon.

The perfect segregation of gas and oil into zones is disrupted somewhat by differential porosity and varying permeability found in the porous medium. The sands of relatively greater consolidation, cementation and compaction offer a possible obstruction to the egress of oil. Since gas is more mobile than oil, it moves more rapidly and precedes the oil, which remains in the adjoining less indurated sands of greater permeability. Therefore, wells completed in sands of this character necessarily have high gas ratios even though casing is set and ce-

mented far below the general gas-oil contact. On the whole, however, the various levels are remarkably uniform and the field almost ideal in its fluid equilibrium.

The average sub-sea level at which gas and oil are in contact in the upper Cockfield sand is at −4,850 feet, in many places being higher than the gas level in the main Conroe sand, although in most instances it is only higher in the northern portion of the field.

OIL-WATER LEVELS

The oil-water level is regularly encountered at −4,990 feet in all sands and is nearly uniform except where there is variation caused by faulting. Like the irregularity of the gas level, the oil-water contact, in the part of the upper Cockfield horizon in the northwestern portion of the dome, ranges from −4,870 to −4,990 feet. The lower level for this small area is probably a result of faulting, since there is a pronounced uniformity in the fluid levels throughout the remainder of the reservoir, as is the case with the gas-oil level.

TABLE IV

ANALYSIS OF TYPICAL CRUDE OIL FROM CONROE FIELD

A. P. I. gravity	38°
Specific gravity	0.835
Sulphur content, per cent	0.05
Viscosity	33/100
Color	Dark green
GASOLINE AND NAPHTHA CONTENT	
Per cent	36
A. P. I. gravity	49°
Octane valve	57
Sulphur content, per cent	0.02
KEROSENE DISTILLATE	
Per cent	20
A. P. I. gravity	36°
Sulphur content, per cent	0.03
R. O. viscosity	475
F. B. P.	490
GAS OIL	
Per cent	24
A. P. I. gravity	32.7°
Sulphur content, per cent	0.09
Flash (P. M.)	250
Pour	30
CRACKING STOCK (HEAVY GAS OIL)	
Per cent	15
A. P. I. gravity	27.4°
Sulphur content, per cent	0.21
Cracked gasoline recovery, per cent	50
BOTTOMS	
Per cent	5
A. P. I. gravity	15.2°
Sulphur content, per cent	0.65

WATER ENCROACHMENT

The rapidity of vertical water migration and the effects of an active hydrostatic head can not be closely estimated at present. If a reservoir of Conroe proportions saturated with a Conroe type crude of 39° A.P.I. is assumed, a withdrawal of 40.1 million barrels of oil would represent a vertical rise of the water table of about 1½ feet. Calculations were made for an ideal case; no corrections were used for gas, oil, or water expansion.

On January 1, 1935, 53 wells in the field were producing water, 35 of which are located outside of the −4,900-foot contour (Conroe sand datum), and are classified as "edge" wells. These wells encountered salt water between depths of −4,975 and −4,990 feet. The porosity of the sand, the degree of oil saturation, and the structural position of the wells, contribute largely to the movement of the water to the well sump. These are normal water wells, and can be expected to appear as the water moves to occupy the space voided by the withdrawal of oil and gas.

The remaining 18 water wells found structurally above the −4,900-foot contour are classified as "inside" wells and the appearance of bottom water above the known water level, −4,990 feet, in these instances, requires a different explanation. Nine of these "inside" wells require still another classification because of their proximity to fault planes. Their water can be explained only by the more or less free vertical passage of connate water up fault planes to and within the oil zone. It has been determined by Schlumberger surveys that the entire sand section in many of these affected wells is contaminated with water. A number of work-over jobs have been attempted on wells of this type, and only in one instance—The Texas Company's Elizabeth Moody No. 18—have plug-back operations been successful. It is known that when salt water appears, the percentages increase from zero, or a small amount, to 50 per cent, and in some instances to 100 per cent, in as short a period as 72 hours. Experience has shown that the only effective method of eliminating water from such wells is to plug the entire sand body and either whipstock out away from the flooded area or drill a new hole 100 to 150 feet away from the fault plane. The latter method was followed in Abercrombie-Harrison's McShane No. 1, and well No. A-1 has been producing pipe-line oil since April 1, 1934, without the reappearance of water.

Some "inside" water wells, not associated with faults, produce water at depths varying from −4,960 feet to −4,990 feet. Water found at these shallower levels may owe its origin to irregularities in the permeability of the sand zones permitting uneven water move-

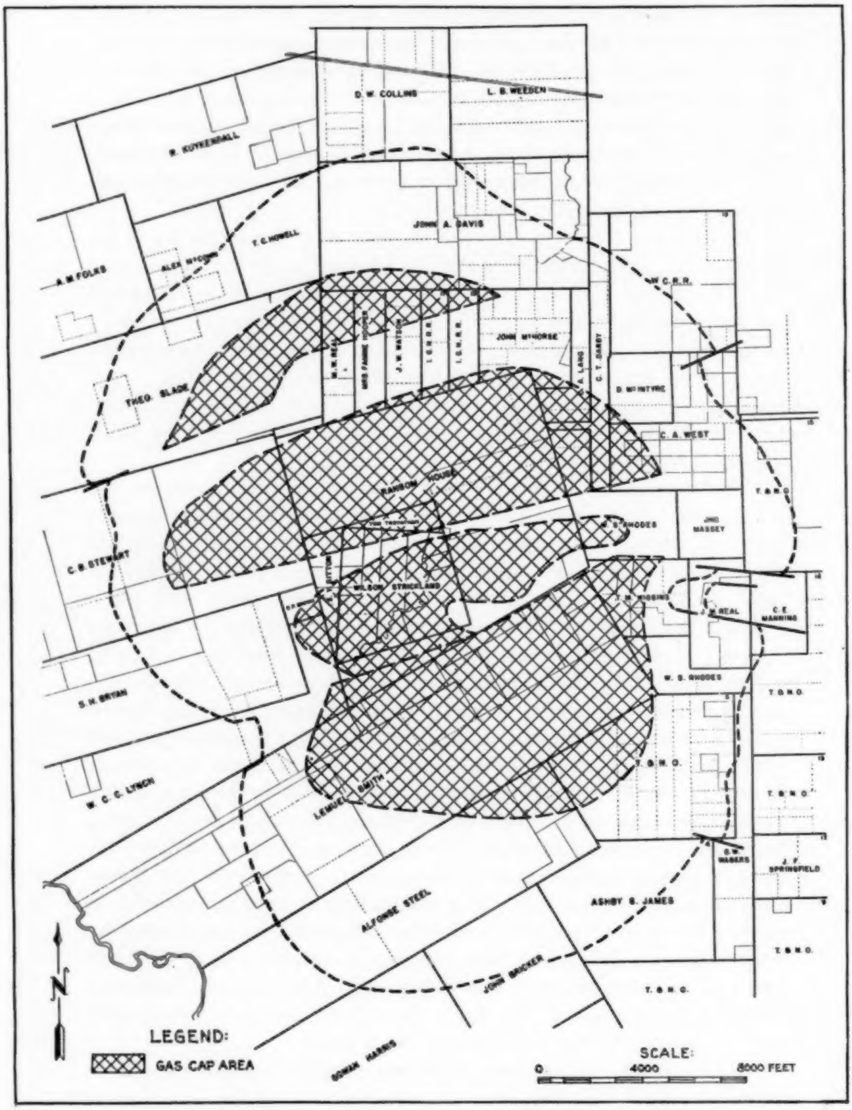

FIG. 7.—Map showing areal extent of gas cap (Conroe sand), Conroe field.

ment. Careful correlations of core records do not disclose a lenticular sand body containing salt water or any sand member likely to carry water at depths shallower than −4,990 feet. Sand conditions unquestionably are the controlling factors in this type of water flooding, and in wells of this nature successful plug-back jobs have been obtained in many instances.

TABLE V

ANALYSIS OF TYPICAL SALT WATER FROM THE CONROE FIELD

SUN COMPANY'S STEWART NO. 3

Primary salinity	89.66
Secondary salinity	9.78
Primary alkalinity	none
Secondary alkalinity	0.56
Per cent rSO_4 in rSO_4 plus rCl	0.06
Ratio rCO_3 to rSO_4	9.33

Constituents in Parts per Million

Sodium	27,620.2
Calcium	1,865.0
Magnesium	553.5
Iron and aluminum oxides	20.0
Sulphate	42.4
Chloride	47,100.0
Carbonate	288.0
Silica	22.0
Total	77,451.1

Reacting Values in Per Cent

Alkalies	
Sodium	44.83
Alkaline Earths	
Calcium	3.48
Magnesium	1.69
Strong Acids	
Sulphate (rSO_4)	0.03
Chloride (rCl)	49.69
Weak Acids	
Carbonate (rCO_3)	0.28

Hypothetically Combined qs	*Parts per Million*	*Grains per U. S. Gallon*
Calcium carbonate	380.0	22.04
Calcium sulphate	60.0	3.48
Calcium chloride	4,696.2	272.38
Magnesium chloride	2,160.0	125.28
Sodium chloride	70,112.9	4,066.55

The area south of the main graben is of special interest, since it contains only one water well above the −4,990-foot contour. This well, the Humble Oil and Refining Company's Moore No. 7, was drilled to a total depth of −4,975 feet, and makes about six per cent salt water. Other wells in this area having similar penetrations are still producing pipeline oil. Perhaps this well forecasts water encroachment in the otherwise water-free territory south of the north line of the Lemuel Smith Survey.

Chemical analyses of all bottom water in the field have been made, and from these data the origin of the water in any well can be determined. Limited data on analyses of upper waters prevent their correlation in many instances, but striking differences from the analyses of the connate waters of the Cockfield permit immediate determination.

GAS CAP

Conroe sand.—A gas-saturated liquid, when associated with additional gas in a reservoir having a pressure equal to, or greater than, the saturation pressure of the fluid, accumulates gas at the apex of the structure, due to its lesser density.

In the Conroe field, faulting was subsequent to gas and oil generation and the resultant contact of the gas-containing upper part of the Conroe sand against shale divided the gas cap, which had formerly been continuous, into four segments (Fig. 7).

Segment I includes the north quarter of the field and is located on the upthrown side of fault F1. It embraces a strip approximately 1 mile wide and 3½ miles long. This strip has an area of 559 acres, an average sand thickness of 25 feet, and a porosity of 26 per cent. Segment II lies north and adjoins fault F2 on its upthrown side. It has an area of 1,840 acres; the sand has a porosity of 28 per cent and is 36 feet thick.

Segment III is located within the graben between faults F2 and F3 and includes 842 acres. The average sand thickness is 29 feet and the porosity is 28 per cent. Segment IV extends southward from fault F3 and occupies an area of 2,004 acres. The sand in this segment is 33 feet thick and is 26 per cent porous.

These four segments contain 5,245 acres, or 181,225 acre-feet of gas-bearing sand in the Conroe horizon. Since 1,932,757 cubic feet of gas is contained in an acre at atmospheric pressure, the reservoir is estimated to have held originally 350,321,670,035 cubic feet of gas.

Upper Cockfield sand.—The upper Cockfield sand overlies the entire dome and comprises approximately 17,400 gas- and oil-producing acres. Of this amount, 14,700 acres, or 84 per cent, contain gas, whereas 2,700 acres are productive of oil. Although faulting affected the upper Cockfield and Conroe horizons alike, the down-thrown segments of the upper Cockfield were not displaced wholly below the gas zone, so that gas is found in this horizon over the greater part of the structure.

This gas cap contains approximately 14,700 producing acres or 117,600 acre-feet of gas sand saturated with 228,292,223,200 cubic feet of gas at atmospheric pressure and temperature. The aggregate of

the two horizons is 298,825 acre-feet of gas sand and 578,613,893,235 cubic feet of gas at atmospheric pressure and temperature.

The commercial importance of this great gas reserve for fuel purposes is small compared with the value of this amount of gas as stored energy to be used in producing oil and in obtaining a higher ultimate recovery.

The Conroe field is now nearly developed and the gas cap has been preserved to obtain a greater ultimate recovery. The gas cap acts as a cushion for stabilizing and equalizing pressure conditions in the reservoir. The maintenance of an even gas-oil level in the reservoir prevents the dissipation of free gas by down fingering and will aid in lengthening the flowing life of wells. When the wells cease flowing and expensive equipment installations become necessary, this gas cap will be invaluable for repressuring purposes, operation of artificial lift devices, and for contributing toward maintaining the same viscosity of the oil to be produced.

RESERVOIR PRESSURES

The study of bottom-hole pressures began almost at the inception of field exploitation and has developed along with the drilling. At the beginning, bottom-hole pressures were used as a criterion for lease valuations, and the bottom-hole pressure commonly was recorded at the completion of every well. Later, readings were taken at periods of 30–60 days, with the wells both shut in and flowing, to make possible a study of their behavior during the intervening time. The older records show a decided tendency toward pressure fluctuation, with recorded variations of as high as 60 pounds in a 30-day period. However, flowing pressures in this period were uniformly the same, and, regardless of the fluctuation in static reservoir pressures, which was due to field adjustment, a steady yielding pressure was maintained while the individual well was producing.

The original reservoir pressure, corrected to 4,800 feet below sea level, was 2,275 pounds per square inch, and was uniform throughout the reservoir.

Development of the field spread away from the discovery producer from northwest to southeast. The first general survey of the reservoir pressure revealed a low-pressure area adjacent to the discovery well, as most of the oil produced during 1932 and the earlier months of 1933 was taken from this portion of the reservoir. This survey, consisting of approximately sixty-five key wells, was taken April 15, 1933, and indicated the pressure to be 2,149 pounds per square inch, or a decrease of 126 pounds from the original pressure. All pressures were corrected to a datum of −4,850 feet (Fig. 8).

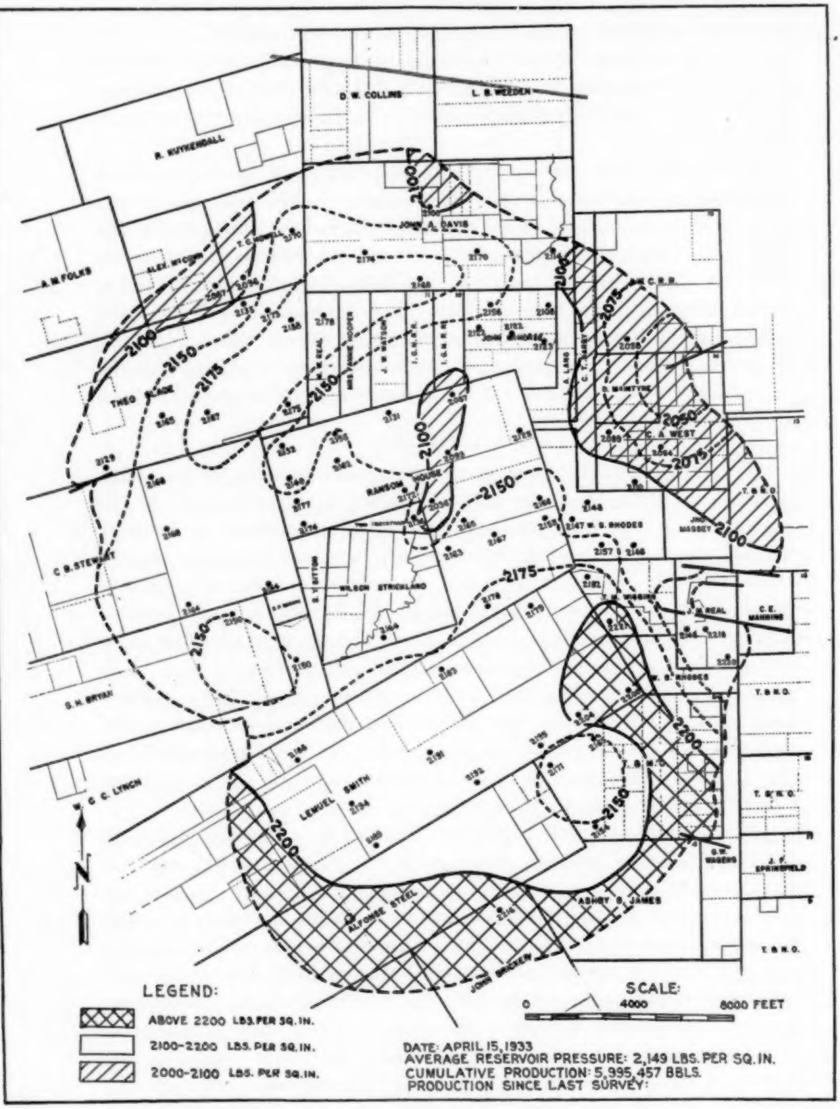

FIG. 8.—Reservoir pressure map, April 15, 1933, Conroe field.

The difference in pressure across the field from northwest to southeast was directly caused by heavy withdrawals of oil from the more densely drilled part of the dome. The pressure change and transfer across the structure from the undeveloped to the developed area resulted in a drop of 50 pounds to the square inch in the undrilled portions of the reservoir. At the time of this survey the field was only 40 per cent developed, which indicates how sensitive is the response of the reservoir to pressure adjustments.

The sharp pressure decline, calculated in pounds per square inch per million barrels of oil produced, is considered a normal phenomenon during the early stages of development for fields of the Conroe type. The decline of pressure in pounds per square inch per million barrels of oil produced from December, 1931, to April 15, 1933, amounted to 21 pounds.

On April 2, 1934, the field contained 742 wells and was 89 per cent developed. The average pressure on this date was 2,095 pounds per square inch at $-4,800$ feet, and the accumulated production was 28.65 million barrels. This represents a pressure decline of 6.3 pounds per square inch per million barrels of oil produced during the producing life of the field on that date. Figure 9 shows the pressure map for this period.

The pressure differential remained in a southeast to northwest direction and showed a difference of only 42 pounds. Equalization of pressures and adjustments in the reservoir were still in progress, indicating the continued influence of high pressures in the southeast on the low-pressure area toward the northwest. The low pressures shown on the map in the T. & N. O. Survey No. 5 are not considered an anomalous condition in the Conroe sand, and are attributed instead to the inclusion of pressure measurements of wells completed in the upper Cockfield sand.

From April, 1934, to January 1, 1935, the reservoir showed no abnormal changes. The pressures were still equalizing and the difference between the northwest and the southeast sections of the field was only 6 pounds per square inch. The areas of highest pressures are found in the territory embracing and contiguous to the gas cap, illustrating proper utilization of the stored gas energy. Many pressure adjustments took place in the reservoir between the April and December pressures of 1934. Energy movement in some portions was intense; yet the weighted pressure decline for the eight months period was only 8 pounds per square inch (Fig. 10).

The accumulated production for the field on December 3, 1934, amounted to 40.1 million barrels of oil, with an over-all field reservoir-

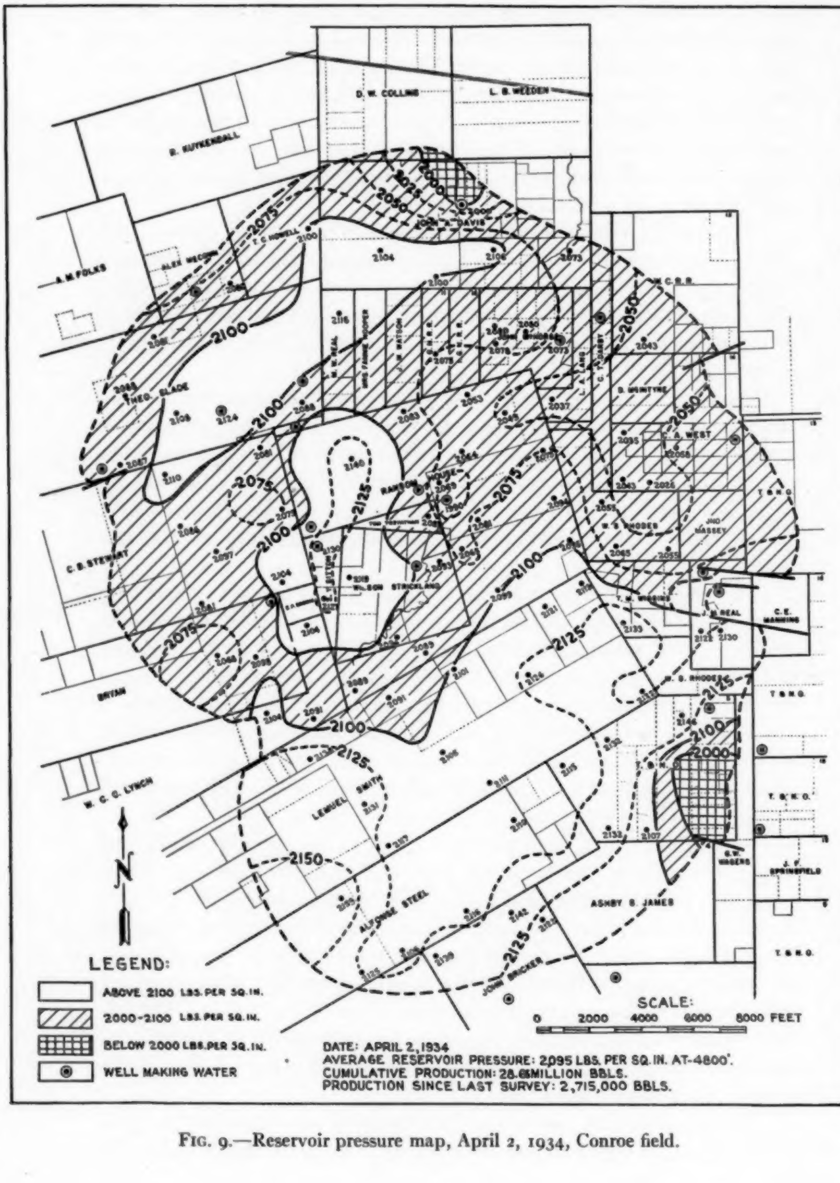

FIG. 9.—Reservoir pressure map, April 2, 1934, Conroe field.

pressure decline of 4.7 pounds per square inch per million barrels. This pressure drop is far greater than that found from April to December, 1934, as this eight months period shows a reduction of only 0.69 pounds per million barrels of oil produced.

The sensitivity of a reservoir, or its ability to equalize pressures, is of chief importance in pressure control. By pressure control, water-coning, gas down-fingering, and oil migration can be minimized.

SOLUBILITY OF GAS IN OIL

The saturation pressure of gas in Conroe crude is approximately 2,300 pounds per square inch at 170°F. Crude samples, taken from the bottom of wells with subsurface sampling devices, show a gas-oil ratio of 600 cubic feet of gas per barrel of oil. Field gas measurements taken on producing wells by either orifice meter or pitot-tube method, closely coincide with laboratory tests when all correction factors for gas measurements are used. Data concerning the solubility of gas in Conroe crude below the saturation pressure, that is, concerning the amount of gas which is liberated by pressure decreases, are not sufficient to construct a solubility curve.

The solution of the problem depends on field observations at the separator under pressure ranges from zero to 200 pounds per square inch, and on observations at numerous wells producing from the upper Cockfield horizon whose pressures had declined below 1,500 pounds per square inch. The first part of the experiment gave the necessary data for the amount of gas liberated in the lower pressure ranges, and these data are checked on numerous occasions under varying conditions throughout the field. Tests conducted on wells producing from the upper Cockfield horizon, and having pressures of 1,500 pounds per square inch or less, have not been thorough enough to permit other than primary conclusions on the behavior of gas in the higher pressure ranges. These data show a negligible liberation of dissolved gas in the reservoir under existing pressures. Thus, a pressure decline of 210 pounds per square inch has freed less than 50 cubic feet of dissolved gas per barrel of oil. The contrary is observed in the lower pressure ranges as experiments indicate a gas release of from 1.5 to 2 cubic feet per barrel per pound decrease from 100 pounds per square inch to atmosphere.

From the analysis of these data the following interpretations can be made.

1. Although the pressure in the reservoir has been reduced 210 pounds per square inch below the saturation pressure, only a negligible quantity of gas has been liberated. Dissolved gas liberation is

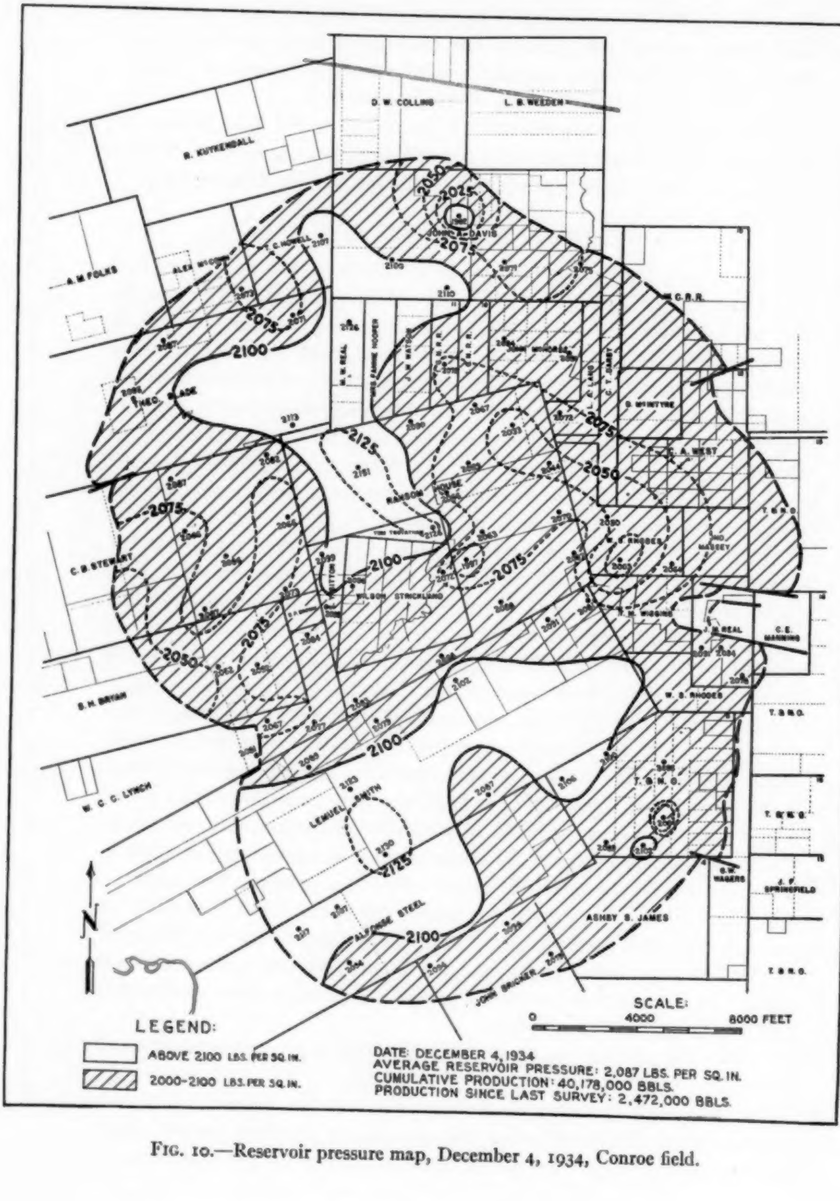

FIG. 10.—Reservoir pressure map, December 4, 1934, Conroe field.

following a definite slope curve that approximates the horizontal for the first 200 pounds pressure drop. Indications are that the curve should continue on its present course until an 800-pound pressure drop occurs, or until the bottom-hole pressure equals 1,500 pounds per square inch.

2. The oil has little ability to hold gas in solution when a pressure of 200 pounds per square inch has been reached and dissolved gas is lost at a rate of 1.5 to 2 cubic feet per barrel for each additional pound decrease. It is inferred, then, that the lower portion of the curve will suffer an abrupt change, which is necessary for an intersection with the down slope of the arc prescribed by the other segment of the curve.

This characteristic of Conroe crude is of great importance, since it places gas-oil ratio control entirely within the limits of mechanical equipment so long as the reservoir pressure is above 1,500 pounds per square inch. Under these conditions, if a well is properly completed and equipped, it is impossible to vary the gas-oil ratio within the well, regardless of the rate of flow. Proof of this statement is readily apparent. Oil enters the well sump, and passes into the tubing, under sufficient pressure to maintain approximately all of the dissolved gas in solution. Thus the liberation of dissolved gas resulting from a pressure drop occurs in the tubing as the oil moves from the bottom of the well to the surface. The amount of dissolved gas liberated before the oil enters a well, either migrates to the top of the sand because of its lesser density, or moves into the well and is produced with the oil. Quantities of gas liberated in excess of 1,500 pounds per square inch are insignificant and have slight effect on gas-oil ratios. Therefore, if wells are completed in such a manner as to exclude those sands in the free gas zone, and the tubing set low enough to insure drainage from the entire exposed oil sand, the gas-oil ratios are minimized. Rates of flow that permit a uniform, slow pressure decline hold the dissolved gas in solution, thus decreasing viscosity and increasing fluidity, and should result in a greater ultimate recovery of oil.

DEVELOPMENT AND PRODUCTION

Active drilling and development of the field was deferred for several months after the completion of the discovery well (Fig. 11). The first failure within the limits of the active lease "play" was the Heep Oil Corporation's Roberts No. 1, completed June 15, 1932. This well, located in the W. H. Harrison Survey, approximately two miles north of the discovery producer, did not define the north or

TABLE VI

ANALYSES OF TYPICAL GAS FROM THE CONROE FIELD

Sample	*Gas from Sun Oil Company's Stewart No. 1*	*Gas from Humble's South Texas Development Company No. A-4*	*Gas from Sun Oil Company's South Texas Dev. Co. No. 1*	*Gas from Feltex and Kirby's Bertrand No. 1*	*Gas from Humble Oil Company's W. M. Williams No. 3*	*Gas from Tide Water Granger No. 1*
Methane (By gas volume)	88.7%	82.0%	91.7%	90.2%	93.5%	87.7%
Ethane (By gas volume)	7.3%	8.5%	4.3%	5.6%	3.6%	4.6%
Propane (By gas volume)	2.4%	5.6%	2.3%	2.4%	1.4%	3.3%
Butane-heavier (By gas volume)	1.6%	3.9%	1.7%	1.8%	1.5%	2.0%
						2.4% pentanes
Observed sp. gr. (Air-1)	0.646	0.741	0.648	0.642	0.639	0.708
Total unsaturate	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Air	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CO_2-H_2S	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Cal. gross heating Val. B.T.U./cu. ft.	1133	1211	1121	1110	1088	1208
G.P.M. butane-heavier	.5	.7	.5	.6	.5	1.5
	500 Gas/oil ratio normal Conroe	325 Gas/oil ratio low Conroe	Gas well Intermediate gas sand	Gas well Upper Cockfield	8000 Gas/oil ratio high Conroe	400 Gas/oil ratio low Upper Cockfield
Trap pressure	300	42	52.5	250	49	14.5
Sample tank pressure	40	40	40	40	40	40

northwest limits of production. The Houston Oil Company-Heep Oil Corporation's Brent No. 1, the Humble Oil and Refining Company's South Texas Development Company No. 18-A, and the Gulf Coast Production Company's South Texas Development Company No. 1, Conroe sand producers, completed August 5, October 28, and November 11, 1932, respectively, approximately determined the extent of the productive territory toward the north and northwest.

The second outpost well of prominence was the Houston Oil Company-Heep Oil Corporation's (now Tide Water Oil Company's) George Hamman No. 1, in the C. B. Stewart Survey, completed August 1, 1932, which extends the field in a southwesterly direction one mile. At about the same time G. W. Strake's (now Humble Oil and Refining Company's) South Texas Development Company No. 3, only 1,600 feet northwest of the former well, encountered salt water in the Conroe sand, and definitely indicated the limits of production toward the west.

Gieseke and Craft's South Texas Development Company No. 1, located in the center of the T. & N. O. Survey No. 9 in the southeast portion of the field, was abandoned August 31, 1932, as a dry hole, at a total depth of 5,502 feet, and the Gulf Coast Drilling and Production Company's South Texas Development Company No. 1, in the T. & N. O. Survey, proved dry. These two failures retarded development in this area until the drilling of the Gulf Coast Drilling and Production Company's Keystone Mills No. 1 in the A. S. James Survey, 6,500 feet west and 2,300 feet north of the Gieseke and Craft failure, completed as a producer in the upper Cockfield sand, October 26, 1933. This completion resulted in a renewal of activity in a southeasterly direction, as the field was actually extended 3½ miles toward the southeast from the Humble Oil and Refining Company's Dobbins No. 1, and 5½ miles southeast of the discovery well.

J. Papadakis' McDonald No. 1, located on a 5-acre tract in the eastern portion of the J. A. Davis Survey, was completed November 19, 1932, and extended production approximately 1 mile east of the Heep Oil Corporation's Freeman No. 1. The Tide Water Oil Company-Strake Petroleum Company's J. W. Lewis No. 1, in the C. B. Stewart Survey, extended production in a westward direction 1¾ miles from the center of the field (Humble Oil and Refining Company's Dobbins No. 1). This well was completed December 6, 1932.

The Alpha Petroleum Company completed its Falvey No. 1 in the G. W. Harris Survey at a reported depth of 5,162 feet in the upper Cockfield sand. This well, though of small consequence as a producer, limited the oil outline on the south and was of major importance as

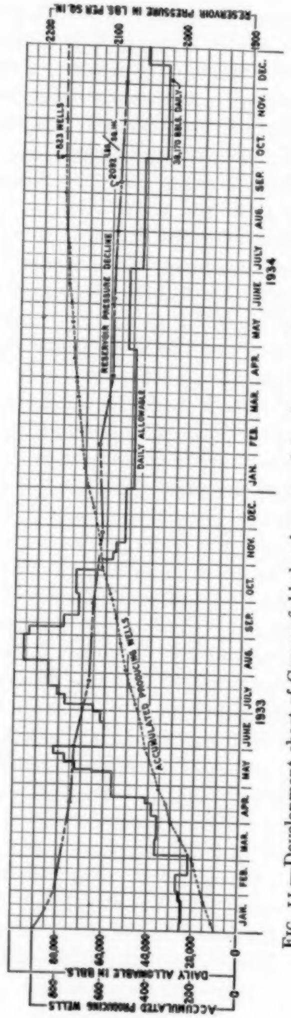

FIG. 11.—Development chart of Conroe field showing rate of development, daily allowable, and reservoir pressure decline for the years 1933 and 1934.

an outpost well. The North Star Oil Company's Granger No. 1, T. & N. O. Survey No. 14, encountered salt water at 5,127 feet, and established the limit of production in this area between that well and the South Gulf Oil Company's Granger No. 2, T. & N. O. Survey No. 9, completed in the upper Cockfield sand, 1,600 feet southwest.

The completion of these edge wells and numerous other producers and dry holes along the limits of production has definitely outlined the areal extent of the Conroe producing sand. The limits of the upper Cockfield sand have been well defined on the south, southeast, east, and west sides of the structure.

Later development by the Sun Oil Company, in the Alfonse Steel Survey, in the southwest portion of the field, has extended the borders of production of the upper Cockfield sand nearly 2,000 feet west. There has been no further effort in this portion of the field definitely to connect this extension to the known limits that exist on the south and west sides of the dome. In all probability the producing limits of the upper Cockfield sand will conform to the general outline of Conroe sand production, and it is expected that production of some sort will be found all along this side of the dome, as has been indicated by wells on the south, west, and northwest.

The greatest development of the Conroe field occurred during 1933. The year began with less than 100 wells producing a total of 25,000 barrels of oil per day, and ended with 679 wells producing 52,500 barrels per day. During the year 21,483,279 barrels were produced. As is shown by the accompanying chart, Figure 11, a rapid production increase began in March, reaching its peak of 82,000 barrels per day in May, followed by a sharp decline the first of June. This rapid increase in daily production resulted from the segregation by the Texas Railroad Commission of the upper Cockfield sand, which was temporarily set up as a separate oil field and was given an allowable of 10,000 barrels of oil daily. Daily production, therefore, rose from 25,000 barrels to 82,500 barrels as a consequence of the new ruling.

By June 1, 1933, the daily allowable for the whole field was fixed at 60,000 barrels to be produced from 420 wells, and the operators were more or less in accord as to the future policies of the field. However, this condition was soon interrupted, and on June 19 production decidedly increased due to the Abercrombie-Harrison's Alexander No. 1 cratered well, which began producing oil out of control, and by August 10 production reached an all-time peak of 92,000 barrels per day. The crater producer reached a peak of 8,000 barrels of oil per day, which caused other operators to insist that the field allowable

be raised, so that they could approximate their expected proportion of oil. These increases, with the unregulated production from the "wild" well, gave Conroe its peak production when the field was only 57½ per cent developed.

The general condition of the oil industry, however, demanded that less oil be produced in all fields, and Conroe received its proportionate reduction, despite the uncontrolled production from the cratered well. The downward trend of the daily allowable curve (Fig. 11) shows these different production reductions by the Railroad Commission in the latter months of the year.

In April, 1933, the first general reservoir pressure survey was made, and gave the starting point for pressure history at Conroe (Fig. 11). Interpolation has to be made for the decline from 2,275 pounds, the original pressure, to 2,149 pounds, the pressure found to exist April 15, 1933. Subsequent surveys have been made every 60 days and have been carried forward regularly.

Drilling activity declined as operators satisfied their lease requirements of 1 well to 20 acres, and at the close of 1934 there were only three active rigs in operation in the field.

Continued production at a uniform rate brought about an equalization in pressure, resulting in the reservoir losing only 8 pounds of pressure while producing approximately the same amount of oil that was produced in 1933. This 8 pounds decline can be compared to the 167 pounds decrease experienced in 1932 and 1933.

DRILLING METHODS AND PRACTICES

All of the drilling at Conroe was done with rotary tools, in accordance with A. P. I. recommendations for straight-hole practice. Weight indicators, straight-hole reamers and, in some instances, oversize drill pipe on the bottom of the drilling string were used, aiding materially in drilling straight holes. Each well was tested for deviation from the vertical every 500 feet. The common practice of measurement was by the Sun-Syfo, Bullseye, or acid-bottle methods. It has been customary also in making contracts to specify that no more than a maximum of 3° deviation from the vertical would be permitted. Strict adherence to these precautionary measures has resulted in most of the wells at Conroe being comparatively straight.

In 1932 the average time for drilling in and completing a producer in the Conroe field was 45 days; in the early part of 1933 it was 30 days and by the end of that year, 22 days.

The accepted casing program includes a surface string of 10¾-inch casing at approximately 1,400 feet. The length of this string depends

on the upper waters encountered above this depth and some few of the latter wells have been completed using a 900-foot string of surface casing. This casing is usually 40½-pound seamless pipe set with enough cement to insure "returns" to the surface. The structural position of the well determines, to a large extent, the amount of 7-inch casing to be set, but the average is about 5,020 feet. This setting requires 26-pound seamless steel, grade C casing. The 7-inch casing is run with a set shoe on the bottom and a float collar, one joint off bottom, to eliminate the possibility of pumping all of the cement out of the casing and to insure the placing of an uncontaminated cement core around the casing shoe.

All drilling is done with rotary equipment of heavy type 94-foot derricks with 24×24-foot bases. The traveling blocks vary from 66 inches to 76 inches and the crown blocks were 4- to 5-sheave roller-bearing type. The 6-inch drawworks predominated and were driven by 12×12-inch piston-cylinder horizontal steam engines. The rotary table was usually a 20-inch roller bearing of either enclosed or open type.

Fuel and water supply were abundant, and in all cases, except in early development, natural gas was used to furnish steam power. Close supervision was maintained over the weight, viscosity, and general condition of the mud at all times. A blow-out preventer was used on both the surface pipe and the oil string. However, some operators use two blow-out preventers on both surface pipe and the oil string, one hydraulically operated and one of the ordinary pack-off type. It has been the usual procedure to test the preventers at least once each day, and one company requires a blow-out drill to be held by each crew at least every tour. On the majority of rigs the mud weight is taken on a specially made hydrometer for this purpose and recorded several times each tour. Other operators use the bucket-and-scales method of determining mud weights. The viscosity of the drilling fluid is usually tested at the same time that the weight is taken. This measurement in most instances is obtained by the funnel-type viscometer.

A continuous study has been made on mud since the beginning of development, and it has been found that practically no natural mud is made above a depth of 700 feet. Spudding operations require commercial clay or mud obtained from some adjoining location. From the depth of 700 to 3,500 feet a good natural 10½-pound mud is made having a low viscosity and low gelatin qualities. At approximately 3,500 feet the mud changes, and below this depth a decrease in natural mud weight is noticed, with an increase in viscosity and gelatination.

This is the critical depth for mud control in the Conroe field and very close supervision is given to mud in all wells when this depth is reached. The present program for Conroe drilling fluids is to carry an average of 9.7 pounds to 10.5 pounds per gallon, thinned to a low viscosity with water or some chemical, thus making it possible for the mud to relieve all entrained gas and reduce the static disturbance caused by a "round-trip."

In the area comprising the southeastern and central portion of the Ransom House Survey and the Wilson Strickland Survey, a gas sand is encountered at about 4,750 feet (top of Cockfield) and the mud weight is built up from a natural 10-pound to 11- or 11½-pound mud, which is carried from that depth to the bottom of the hole, maintaining the viscosity as low as possible by thinning with water or chemical. Better mud control is actually obtained by using a 9.7-pound mud at this depth, with stress given to a very close study of the viscosity to assure fluidity.

It has been found that by proper chemical treatment of the mud before setting 7-inch casing, the pump pressure can be lowered approximately 200 pounds, thus insuring a better setting for the 7-inch casing.

BLOW-OUTS

Shallow gas deposits of small volume, but abnormally high pressures, were the first indications that difficulties lay ahead in deeper drilling. These gas deposits probably owe their origin to vertical migration of gas from the Cockfield formation along the fault planes, where permeable sand bodies in the Catahoula and younger formations have permitted horizontal movement of this gas and allowed accumulation to become unusually great in certain areas.

One well, completed to a total depth of 5,119 feet, while waiting for cement to set on the 7-inch casing, blew out between the oil string and the 10-inch casing. Escaping gas with velocities great enough to carry sand in suspension soon cut away the surface connections and ignited the well. Before the fire could be extinguished a crater began to form. The loose unconsolidated surface deposits offered little resistance to this extreme gas release and the crater soon had a diameter of 200 feet. Horizontal gas migration through shallow water-bearing surface sands caused veritable geysers to form in the bed of Crystal Creek and innumerable fresh-water springs considerably increased their flow.

Gas seeps appeared around a completed oil well 1,600 feet northwest of the crater and within three days the surface connections had

submerged into a crater 180 feet in diameter. This well remained dormant five months after the crater had ceased rolling and then began producing oil. Production reached a peak of 10,000 barrels of oil per day and the well produced 1,465,380 barrels of oil in 6½ months before it was shut off finally by the drilling of a deflected well located 427 feet northeast of the crater, through which water was injected into the producing sands.

The following table shows the outstanding wells of blow-out importance, the date of occurrence, and depth where the blow-out occurred.

TABLE VII

Company	*Well*	*Date*	*Depth in Feet*	*Result*
Alpha Petroleum Co.	R. R. Dunn No. 1	8-24-32	4,518	Blow-out, killed with baroid
Showers-Moncrief	R. R. Dunn No. 1	10-1-32	1,240	Caught fire, abandoned
Gulf Coast Drilling Company	Keystone-Mills No. 1	10-25-32	5,001	Blew wild 2 days before killed
Texas Company	Moody No. 5	12-13-32	1,104	Blew wild 2 days before killed
Southland Oil Co.	Cummings No. 2	1- 8-33	5,076	Blew wild 2 days before killed
Standard Oil Co. of Kansas	Madeley No. 1	1- 8-33	5,119	Caught fire, cratered, abandoned
Standard Oil Co. of Kansas	Madeley No. 2	1-17-33	985	Caught fire, cratered, abandoned
Abercrombie and Harrison	Alexander No. 1	1-26-33	5,160	Cratered
Texas Company	Rhodes No. 4	4- 1-33	5,000	Wild 8 days, abandoned
Humble Oil and Refining Company	Pfaefflin No. 5	5-19-33	5,000	Wild 5 hours
Humble Oil and Refining Company	Madeley No. 24	9-21-33	5,134	Caught fire, cratered, abandoned
Humble Oil and Refining Company	A. Moorehead No. 3	12-13-33	960	Caught fire, cratered, abandoned

WELL SPACING

Well spacing regulations at Conroe require the drilling of one well on each 20-acre unit. However, 108 exceptions to this order have been made which represent 13 per cent of the total wells completed. Of this total 61, or 7.35 per cent of the producers, are on tracts of less than 20 acres, subdivided prior to the discovery of the field. Since the Railroad Commission did not grant any additional allowable for wells on tracts larger than 20 acres, additional wells had to be drilled on fractional units to satisfy lease requirements when the acreage of

the tract was not a multiple of 20. The remaining 47 wells are in this class. These exceptions, with their acre spacing and allowables, are listed in Table VIII.

TABLE VIII

Number of Wells	*Number of Acres*	*Barrels per Day Allowable*
2	3	30
1	4	34
6	5	37
2	6	39
3	7	41
4	8	43
2	9	44
33	10	46
3	11	47
7	12	50
2	13	51
4	14	52
13	15	53
6	16	55
5	17	58
2	18	60
13	19	63

Final analysis of the regulatory measures beneficial to Conroe development must attribute great importance to uniform well spacing. The thickness, porosity, permeability, and saturation of the sand are the dominating factors for any well-spacing program. The effective well distribution on the producing sand is the controlling factor in well interference.

Rapid drilling and uniform spacing gave the reservoir an equal density by the end of 1934, and allowed the whole reservoir to produce its potential allotment and resulted in ratable withdrawals of oil and gas.

Pressure records of recently completed wells have substantiated the general accepted belief that one well is adequate to drain 20 acres. Initial pressures on new wells conform to the average pressure of the area instead of approaching the original static pressure, proving that well interference has been sufficient to disturb the reservoir equilibrium.

PRORATION

Proration in its broadest sense covers field regulation conservation measures, including mechanical equipment of wells, and designates also the amount of oil to be taken daily from each well and from the field proper. Statewide regulation orders adaptable to oil fields are, in the main, regulation orders providing for good operation practice. The preamble of these orders permits exceptions to all rules at the

discretion of the Texas Railroad Commission, and each field is considered a separate problem and has its own individual field regulations.

Proration at Conroe began with emergency orders, establishing drilling practices, casing procedure, and well spacing, that were issued in June, 1932, when the field had less than six producing wells. As in all fields, Conroe's proration difficulties grew as additional wells were drilled, and by February, 1933, these contentious problems had resulted in several major infractions of the regulations. Serious problems of dispute were heard before the Railroad Commission and an allocation of production based on acreage was inaugurated. The original allocation plan treated each 20-acre tract as a unit of production, all receiving the same amount of oil. Fractions of a unit, or tracts of less than 20 acres, were reduced according to their proportion to the whole.

A daily allowable of 22,000 barrels of oil divided among the producers in the field permitted the production of 420 barrels a well. This well allowable was reduced as new wells were drilled and by March 1, 1933, 219 wells had been completed, each having a daily allowable of approximately 100 barrels per day. Further drilling development constantly reduced the well and acre allowables until it became apparent that an increase in the field allowable was an economic necessity. These problems of dispute regarding the proper top field allowable and the method of allocation were heard before the Railroad Commission in the spring of 1933.

Another question of regulation arose in March of 1933, when operators owning upper Cockfield sand production maintained that their producing horizon was separate and distinct from the Conroe sand horizon, and therefore should be given a separate allowable. A questionable interpretation of the then existing proration orders led to an application wherein it was requested that no production regulation be applied until after a 10,000-barrel daily withdrawal was reached. Although granted at first, this application was rescinded when a public hearing was held and satisfactory proof given that the two producing horizons were connected with both producing levels adjacent to one another due to faulting.

Pending injunction suits testing the validity of proration orders at Conroe brought about the only alteration in the Conroe method of allocation. Prior to the hearing of these cases on interlocutory injunction, the proration plan was changed from a 20-acre unit plan to one where well allowables were based 50 per cent on acreage, with 20 acres still as a unit, and 50 per cent on potentials taken through

a ¼-inch positive choke for 24 hours. Seventy-five wells were chosen as key wells for the original survey, with the understanding that all additional wells drilled in the field would be tested for their own individual potentials.

An interlocutory injunction hearing, held before a three-judge federal court in July, 1933, resulted in a favorable decision for the defendant, the Railroad Commission; and the plaintiffs, J. Papadakis, Hamill and Smith, W. W. Hawkins, et al., were denied their plea for a permanent injunction. This decision was most important for proration at Conroe and no further attempts have been made to set aside the existing order.

The top allowable for the field is based on the share allocated to Conroe of the total state allowable recommended by the Federal Oil Board. This allowable, 47,700 barrels daily, is divided among 829 wells producing daily amounts proportional to their 24-hour ¼-inch choke potential and their drainage according to 20-acre well spacing. The average allowable is 52 barrels per day for a well satisfying a 20-acre unit. Through proration, which has been invaluable at Conroe, the greatest possible ultimate recovery from the field will be obtained.

The importance of gas conservation, proper use of reservoir energy, control of salt-water migration, and proper completion of wells, and their direct results upon ultimate recovery, have been stressed in every meeting of the field producers and the State enforcement officers. Regulations requiring proper casing setting, uniform well spacing, minimum gas-oil ratios, control of salt water, and ratable withdrawals of oil and gas, are directly responsible for Conroe being an outstanding success in efficient operation under proration.

METHOD OF PRODUCING WELLS

Flowing wells.—The flowing wells at Conroe offer no unusual producing problem, and each operator obtains his production in the manner that will best meet his lease requirements and storage facilities.

A total of 69½ per cent of all wells in the field are connected with gasoline plants and the production of these wells is controlled to comply with the requirements of the gasoline extraction plant. One of the plants is equipped with a vacuum system, and wells connected with this plant produce through a small choke over a 24-hour period. The trap pressure is maintained at that of the atmosphere, and the separator gas conducted to the gasoline plant through a vacuum system.

The other plant requires 35 pounds pressure to put gas into its system, and all wells are operated with at least 35 pounds of pressure at the separator. Production from these wells is taken intermittently in rotation on the lease, the allowable is obtained in from 6 to 12 hours, and the well closed in for the remaining time of the period. In all instances production is obtained through tubing, and with either an adjustable bean or a positive choke of proper orifice to control the flow in accordance with the allowable. Some slight paraffine accumulation is noted during the winter months, but it has been found that this accumulation can be removed by a faster rate of flow for a shorter period of time.

Artificial-lift wells.—There are three types of artificial lifts in use in ten wells at the present time.

A pumping unit power by either electric or individual gasoline engine having a 12-foot working barrel and ¾-inch sucker rods is in operation in six wells. The length and frequency of the strokes is individual for each well. Well spacing where large fluid volumes must be handled causes difficulties in pumping from 5,100 feet. Sucker rod crystallization and excessive wear on working barrel parts are common occurrences.

One installation of the Hughes plunger lift is in operation. Additional gas for working pressure is obtained from flowing wells on the same lease. The remaining three wells are operated by multiple stage lift or flow valve devices; injection of gas from an outside source is necessary for their operation.

Lifting cost records have been kept on these three methods of production, but the time of operation which has elapsed has been too short to afford a comparison of economy or efficiency.

PIPE LINES

The Conroe field is amply served by pipe-line facilities. Five pipe lines having aggregate capacity of 115,000 barrels a day connect the field with refineries and sea terminals. Two of the trunk lines which connect Conroe with tide-water may be classified as purchasing lines. These lines serve practically all of the non-integrated companies in the field. These lines, the Tide Water Pipe Line Company and the Channel Transport and Pipe Line Company, terminate on the Ship Channel east of the city of Houston. The crude is transported coastwise for refining on the Atlantic seaboard and for foreign commerce. The Channel Transport and Pipe Line Company depends largely on spot contracts for crude disposal, while practically all of the Tide Water Company oil goes to its eastern refinery.

The remaining three pipe lines operating in the field carry the parent company's production. These lines, Humble Pipe Line Company, Texas Pipe Line Company and Sun Pipe Line Company, terminate respectively at Baytown, Texas (Humble Refinery); Houston (Texas Company Refinery); and Sabine, Texas (Sun Company's sea terminal).

These pipe lines are fed by eight field gathering systems listed as follows.

TABLE IX

Pipe Line Company	*Gathering System*
Channel Transport and Pipe Line Co.	Abercrombie-Harrison Adeloil Beta Federal
Humble Pipe Line Company	Humble
Texas Company Pipe Line Company	Tidal Texas Company
Tide Water Pipe Line Company	Tidal
Sun Pipe Line Company	Sun

A short line connecting the field with a railroad loading rack has not been in operation since 1933 and all of the oil from the field is now transported through the five trunk line connections.

TABLE X

PERTINENT DATA, CONROE FIELD

JANUARY 1, 1935

1.	Producing acreage		15,711 acres
2.	Total productive acreage		17,200 acres
3.	Conroe sand acreage		14,500 acres
4.	Upper Cockfield sand acreage		2,700 acres
5.	Oil reservoir content		862,120 acre-feet
6.	Original recoverable reserves		606,980,000 bbls.
7.	Number of producing wells		829
	(a) Conroe sand wells	776	
	(b) Upper Cockfield sand wells	53	
	(c) Gas wells	8	
	(d) Shut-in wells	8	
	(e) Pumping wells	10	
	(f) Dead wells	2	
8.	Cumulative production to January 1, 1935		40,100,000 bbls.
9.	Production rate, January 1, 1935—per day		47,700 bbls.
10.	Field potential ¼-inch choke—per day		389,975 bbls.
11.	Largest potential well Neversuch Oil Co. S.T.D. Co. No. 3—595 bbls. per day, ¼-inch choke		
12.	Average reservoir pressure December 1, 1934		2,083 lbs.
13.	Average reservoir pressure decline, April 15, 1933, to September 27, 1933		31 lbs.

TABLE X (*Continued*)

14. Average reservoir pressure decline, April 1, 1934, to October 1, 1934		3 lbs.
15. Number of high gas-oil ratio wells		7
16. Number of wells making water		53
17. Number of wells re-worked		45
18. Number of acres in gas cap (Conroe sand only)		5,411
19. Original volume of gas cap (Upper Cockfield and Conroe sands)		578,613 billion cu. ft.
20. Daily gas production		30 million cu. ft.
21. Capacity of gasoline plants		
(a) Humble	6.72 million cu. ft.	
(b) Midland	12.5 million cu. ft.	

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OIL POOL OF OPEN RESERVOIR TYPE[1]

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ABSTRACT

It has been stated that no commercial accumulations of petroleum have been found in areas where the controlling structure is a simple terrace in the reservoir sand. That is, in all pools located on apparent terraces, trapping is caused by buried closure or by variations in the porosity of the reservoir rock.[3] In most instances, this is undoubtedly true. However, pools are known in which open terraces are the only causative structures for retaining the oil in place. The Wheat pool is believed to be an example of this type. A description of the geology is followed by suggestions as to the possible origin and maintenance of such an accumulation.

INTRODUCTION

The Wheat pool is located near the center of the Delaware Basin on the east side of Pecos River in southwestern Loving County, Texas. The pool lies partly in the river valley and partly on the slopes of the caliche-covered hills on the east. Surface elevations range from 2,670 to 2,790 feet. The productive area at the present time covers slightly over 5,000 acres.

Production comes from the "Frijole" formation and from the upper sands of the Delaware Mountain group, both of Upper Permian age. Geologically, the pool is interesting, because the oil occurs on a structurally open terrace and because it is one of the few sandstone pools in the Permian Basin, an area principally noted for its limestone production.

ACKNOWLEDGMENTS

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HISTORY OF DEVELOPMENT

The discovery well in the pool was the Ramsey Toyah Bell No. 1. This well, which was located by Wallace Lee, was spudded in June, 1920, and finally, because of bad casing and improper drilling, was

[1] Read before the Association at the Tulsa meeting, March 20, 1936. Manuscript received, January 16, 1936.

[2] The California Company.

[3] W. B. Wilson, "Classification of Oil and Gas Reservoirs," *Problems of Petroleum Geology* (1934), pp. 433-45.

abandoned in 1925, after having flowed several heads of oil. The second well was the Pecos Valley Wheat No 1, spudded in 1924 and completed as a 10-barrel well in 1925. The Lockhart Allen No. 1, drilled in 1926, was also a small well until it was successfully shot in November, 1927. The Wheat well was then successfully shot and also made a 100-barrel well. The shooting of these two wells revived interest in the area. At present, about ninety wells have been drilled, about seventy-five of which are producers.

GEOLOGY

Surface relief does not exceed 150 feet. The Pecos Valley flat is uniformly level and the bordering hills are slightly rolling. A thick surface deposit of caliche, alluvium, and wind-blown sand buries the outcrops of the older formations, and there is no surface evidence of local structure.

SUBSURFACE STRATIGRAPHY

Subsurface formations encountered in the wells belong to the Cenozoic and to the Upper Permian. Relations of the various beds are shown on the accompanying cross sections. Formation samples were collected from most of the wells and these have been examined

FIG. 1.—Relation of Wheat pool to main producing area of Permian basin.

microscopically. The stratigraphy is so simple and the sequence so nearly uniform that accurate correlations can be made from the drillers' logs of those wells from which no samples were collected. No fossils have been noted in any of the formations within the pool. Correlations are based on lithologic similarity and continuity of beds.

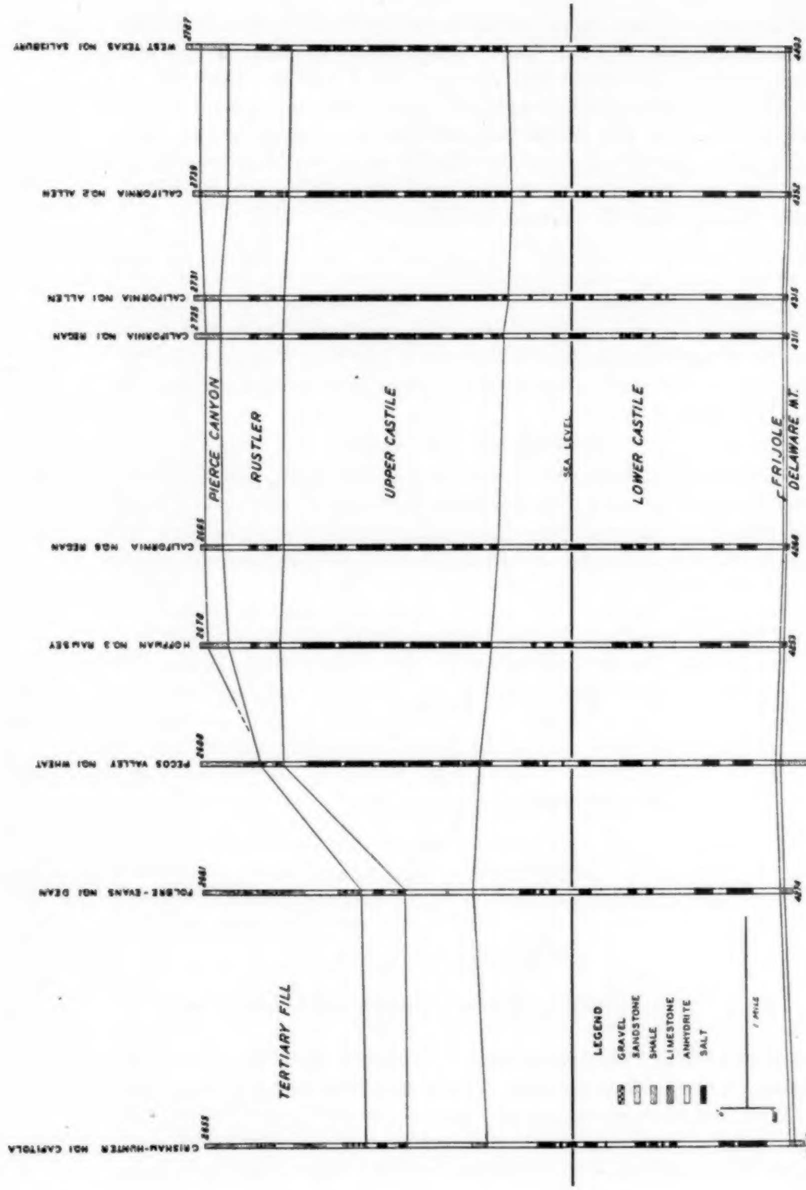

FIG. 2.—North-south cross section, Wheat pool. Thick Tertiary at south end of section fills trough left by salt solution.

The section encountered is characteristic of the central portion of the Delaware Basin. Cross sections (Figs. 2 and 3) illustrate relationships of the various formations.

CENOZOIC

Beds of alluvium, caliche, and wind-blown sand are present at the surface over the main portion of the pool. Near the southwest edge of the productive area these beds thicken up to 1,300 feet. They are characterized throughout by a typical heterogeneous mixture of terrestrial sand, gravel, silt, gray and red shale, limestone and gypsum. In some of the wells farther south in Reeves County, reworked fossils from several Cretaceous formations are found jumbled together with the other clastics.

PERMIAN

Pierce Canyon.—The upper 70 to 120 feet of beds immediately underlying the surface deposits are Permian in age. They are composed of fine red sands and silts with a few thin stringers of secondary gypsum. No Triassic is present in the pool.

Rustler.—The Rustler formation, varying from 370 to 400 feet in thickness, is made up of two main members. The first is an anhydrite or bedded gypsum between 185 and 200 feet thick. There is a thin stringer of sandstone about 50 feet below the top. Euhedral quartz crystals are common in several zones in the anhydrite. The lower member of the Rustler is a dolomite-sandstone-anhydrite series between 185 and 210 feet thick. It is divided into three parts, an upper oölitic dolomite, a middle sandstone-anhydrite zone, and a lower non-oölitic dolomite.

Upper Castile.—The Upper Castile is the main salt series of the Delaware Basin. The thickness of the formation in the pool is between 1,500 and 1,600 feet. Numerous beds of anhydrite are interspersed with the salt. Bands of polyhalite are present, but the main potash beds of the New Mexico section are missing. Either they were never deposited or they were eroded away before the deposition of the Rustler. The name Salido halite has been used to designate the potash-bearing members of the Upper Castile. This member is poorly developed in the Wheat pool and only locally recognizable elsewhere in the basin.

At the southwest edge of the pool all the Upper Castile salt has been dissolved away by circulating waters. The resulting slump has carried the Rustler down about 1,300 feet below its normal structural position. The solution trough, thus formed, is filled with the thick section of Cenozoic deposits mentioned above. Slumping was accom-

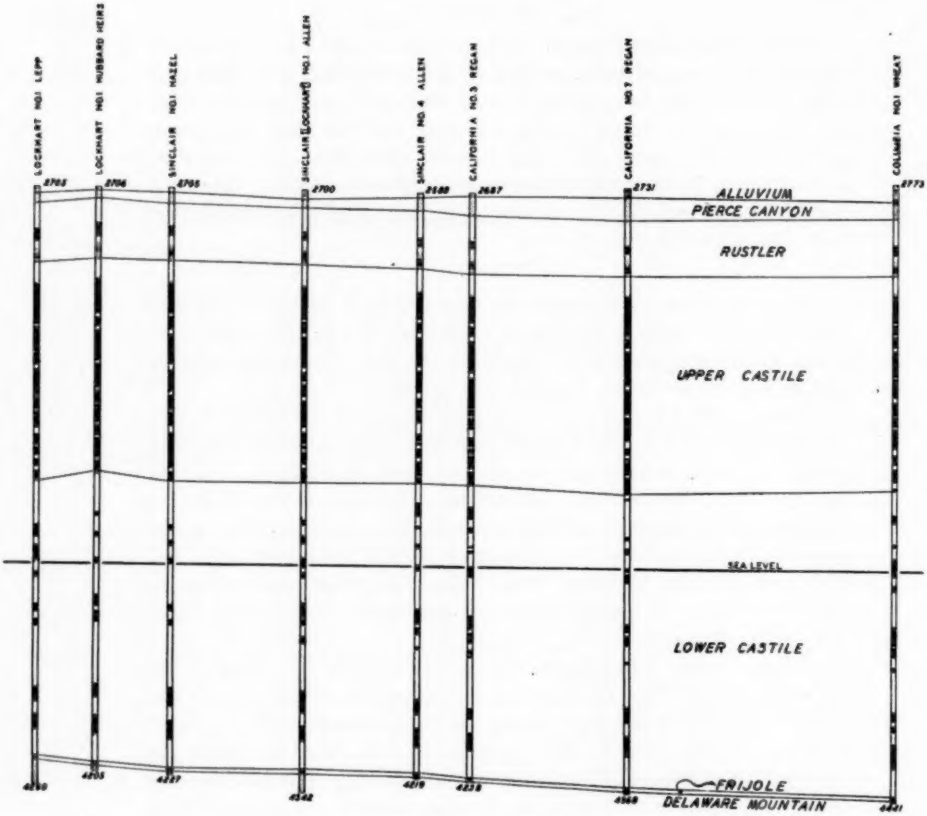

FIG. 3.—East-west cross section, Wheat pool.

panied by fracturing, which allowed some gravel and sand to filter down into the anhydrite section.

The base of the Upper Castile is located in most cases at the base of the main upper salt section. Cartwright[4] placed the contact about 200 feet lower in the column, but it seems that in the Wheat pool, at least, the sharpest lithologic break occurs between the base of the upper salt and the top of the underlying granular white anhydrite.

Lower Castile.—The upper member of the Lower Castile is a 200-foot bed of granular white anhydrite which grades downward into a section of calcite banded anhydrite interbedded with salt. The average thickness of the Lower Castile in the pool area is about 2,000 feet. The carbonate in the Lower Castile is calcite. The carbonate in the Rustler and Upper Castile is all dolomite in this part of the Delaware Basin.

Four groups of salt beds are recognized in the Lower Castile. The salts of this formation are free from potash. The lowermost salt is uniformly from 183 to 185 feet above the base of the anhydrite. Because of its regularity, it is used as a marker in selecting a casing seat for the last string of pipe.

Frijole.[5]—The "Frijole" shale is the upper, thin, dark, clastic member of the Delaware Mountain group. Cores in pool wells show that the formation is made up of three members. The upper 23 feet is hard, dense, black silt or silty shale. The next 7 feet is hard, fine-grained, thinly laminated sandstone. This is succeeded by a 1-foot bed of dense, hard black shale. The formation is extensively shattered in some local areas and many of the cracks are filled with veins of coarsely crystalline white calcite.

Delaware Mountain.—The clastics which underlie the "Frijole" are very fine grained. Mechanical analyses show that about 70 per cent of the material is very fine sand with grain diameters ranging from $\frac{1}{8}$ to $\frac{1}{16}$ millimeter. The remaining 30 per cent is mostly silt. Wells in the pool have penetrated almost 600 feet of sandstone without apparent changes in the character of the material. Farther west, the Delaware Mountain group has a known thickness of somewhat over 3,600 feet. The upper part of this thick sand body is notable for the wide extent and uniform bedding of the individual members. The regularity of bedding and fineness of texture, coupled with the presence

[4] Lon D. Cartwright, Jr., "Transverse Section of the Permian Basin of West Texas and Southeast New Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14 (1930), pp. 969–81.

[5] The name Frijole is locally misapplied to the black shale, encountered in wells, at the top of the Delaware Mountain section. Because of the lack of a suitable name, Frijole is used in this incorrect sense throughout the present paper.

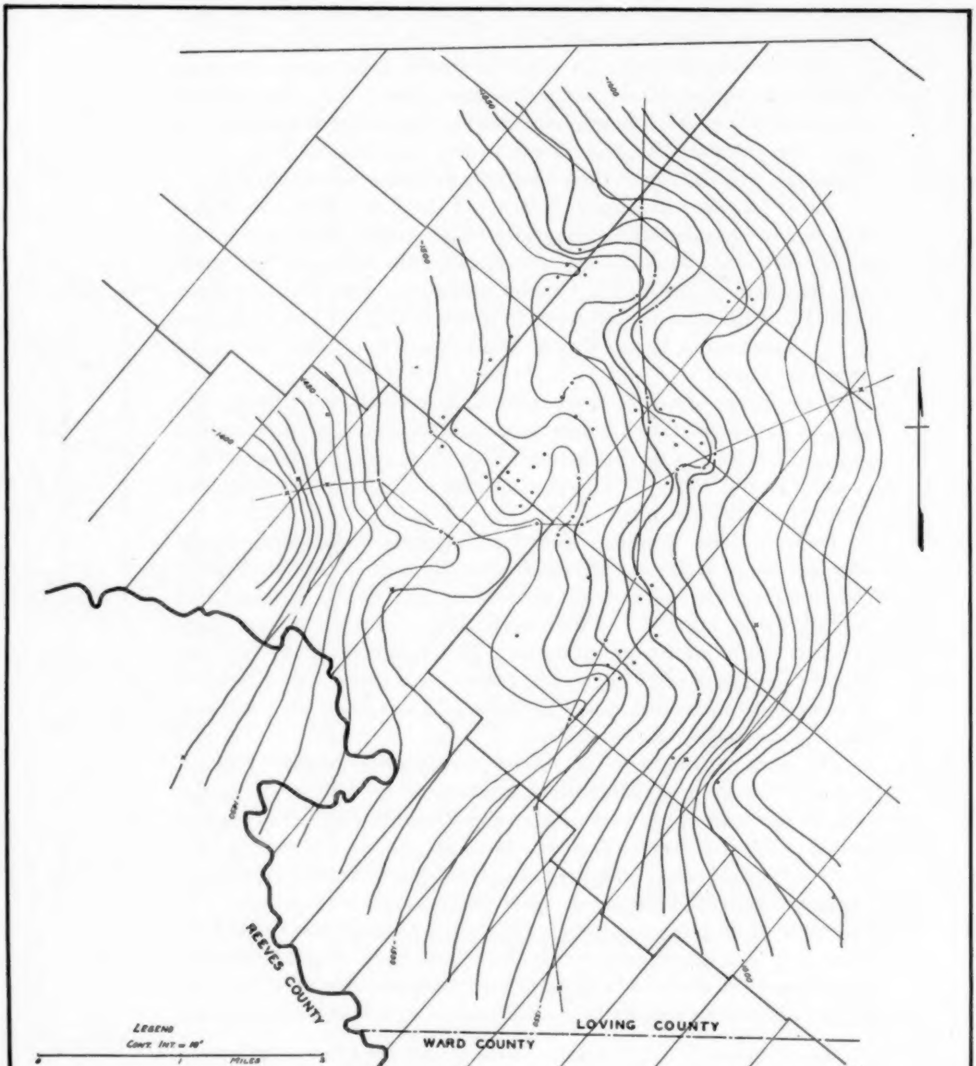

FIG. 4.—Structure of Wheat pool contoured on "Frijole."

of interbedded black clastics and other structural and lithologic evidence, strongly suggest that these beds were deposited in deep, quiet water.

STRUCTURE

As already mentioned, there is no surface evidence of structure in the vicinity of the pool. Subsurface structure is usually mapped on the top of the "Frijole," the "black lime" of the field. The Rustler is not used because the solution slumping which modifies the position of this bed is not reflected in the deeper formations. The pool structure is a wide flat terrace on the west flank of the Delaware Basin. Several small noses are superimposed upon the main terrace. There is a marked steepening of the dip near the east edge of the producing area. At present, there is no evidence of west closure. Dry edge wells on the northwest, west, and southwest flanks are all higher structurally than adjacent producers. The accompanying map (Fig. 4) shows one interpretation of the structural conditions.

OIL, GAS, AND WATER

The oil from the pool is green, 36° gravity, and practically free from sulphur. Commercial production is at present limited to the upper Delaware Mountain sands and the overlying "Frijole." The sand was probably the original reservoir. Cores show that the shale is non-porous except for cracks. In most of the wells the cracks and fractures (joints) are partially or entirely filled with secondary calcite. The wells which produce normally from the shale apparently encountered open fractures. These natural cracks, or the artificial cracks produced by shooting, furnish much better gathering systems than are possible when only the underlying sand is disturbed. The largest wells in the pool are those which produce naturally from this upper formation.

The highest gas volume from any well in the field was slightly over a quarter of a million cubic feet. The gas is sweet and contains small quantities of gasoline. Only a small amount of gas has ever been produced.

The thickness of the pay in the pool is not known. Wells encounter water with the first oil and the amount increases with depth. Carefully tested wells have been drilled more than 20 feet into the sand without striking bottom water. The deep wells in and around the pool either encountered no oil or were drilled through the pay zones with a hole full of water. The conditions under which the water occurs in the sand are not known. It may occupy small pores between the sand

grains and be displaced only when the well is flowing, or it may be present in the finest sandstone beds or laminae, from which, because of its higher surface tension, it is able to displace the oil. Edge and bottom water invade the formation with depletion of the oil. Wells outside the producing area fill with salt water and occasionally flow.

DRILLING METHODS AND PRACTICES

Most of the wells in the pool have been drilled with cable tools. The average drilling time is approximately two months. Water is not readily available for rotary drilling. Besides, the low reservoir pressure and small amount of gas are not favorable for drilling in with a hole full of water or mud.

A 16-inch conductor is cemented in the caliche. Water shut-off is secured by cementing or mudding 10¾-inch casing in the first solid anhydrite below the Rustler. The 7-inch casing is cemented in the anhydrite below the last salt at depths between 4,000 and 4,200 feet.

The wells are irregularly spaced. Close spacing, such as 1 well to 10 or 20 acres, decreases the initial production and interferes with the production of the surrounding wells. This suggests a higher degree of permeability than would be expected in such a fine-grained sandstone reservoir.

PRODUCTION PROBLEMS

All the wells in the field came in flowing, although many are now being pumped. New wells are tubed with 2-inch tubing. Some wells are allowed to flow open; others are operated with some back pressure. Back pressure seems to have been effective in increasing the production and lengthening the flowing life of the wells.

The most serious problem is paraffination of the tubing. Ordinary strings of 2-inch tubing are affected in from 3 to 8 months. Most of the paraffine is deposited in the upper 1,500 feet of tubing, with the greatest accumulations in the uppermost 250 feet. Heating the oil and scraping the tubing produce only temporary relief. Production is not great enough to justify expensive apparatus.

Another problem is the formation of gypsum crusts in the casing, tubing, and working barrel. Gypsum is probably in solution in the water and is precipitated by decrease in pressure. The gypsum accumulations freeze the tubing to the casing and decrease the effective diameter of the tubing itself. No satisfactory method of removing the gypsum has been developed.

Separation of the oil and water is most easily effected by heating and most of the operators have heating plants for this purpose.

GEOLOGICAL HISTORY

Near the close of Delaware Mountain deposition, the earliest period for which we have knowledge of the local history of the Wheat pool, the Delaware Basin existed as a deep depression almost completely surrounded by limestone reefs and shallow lagoons. The outline of the basin was roughly elliptical with a length of about 150 miles and a width of 80 miles. The water in the basin was too deep for extensive limestone deposition, but some fine clastic material was carried in from the surrounding areas. Only the very finest sand and silt were carried out to the center of the depression. Much of the sand is fine enough to suggest transportation and distribution as wind-blown dust.

Initial differences in relief between the floor of the basin and the crests of the surrounding reefs were perpetuated and increased by the same sedimentary processes which made the basins and reefs possible. The Delaware Basin was a long way from any extensive source of clastics. It was separated from this supply by a series of limestone reefs and wide lagoons. The reefs, held together by an organic framework, were protected from disruptive wave action by a mat of algae. As the Permian area subsided the reefs grew upward, keeping pace with the rising water level. At all times they acted as retaining walls holding up the soft limestone muds and such supplies of terrestrial clastics as accumulated in the lagoons. Some material was washed or blown over these barriers, but the amount was limited. Thus the Delaware Basin was destined to continue as a hole in the sea bottom until the type of sedimentation changed. The writer believes that, in the center of the basin, the bottom was between 1,800 and 2,400 feet below the level of the Permian sea at the close of "Frijole" deposition.

Causes which produced the change in deposition from "Frijole" black shale to Castile evaporites can only be surmised. Free connection between the Delaware Basin and the open sea was interrupted, possibly by the building of sedimentary barriers rather than by structural movements. Infiltration of sea water continued, but the concentrated brine behind the barriers killed off the reef organisms and caused the precipitation of anhydrite and salt as well as of limestone and dolomite. The limestones in the Lower Castile may have been deposited while the water in the basin was still fairly deep. The dolomites of the Upper Castile are shallow-water deposits laid down after the Delaware hole had been filled.

Structural movements affecting the Wheat area were of two types—local and regional. The arrangement of Delaware and Castile

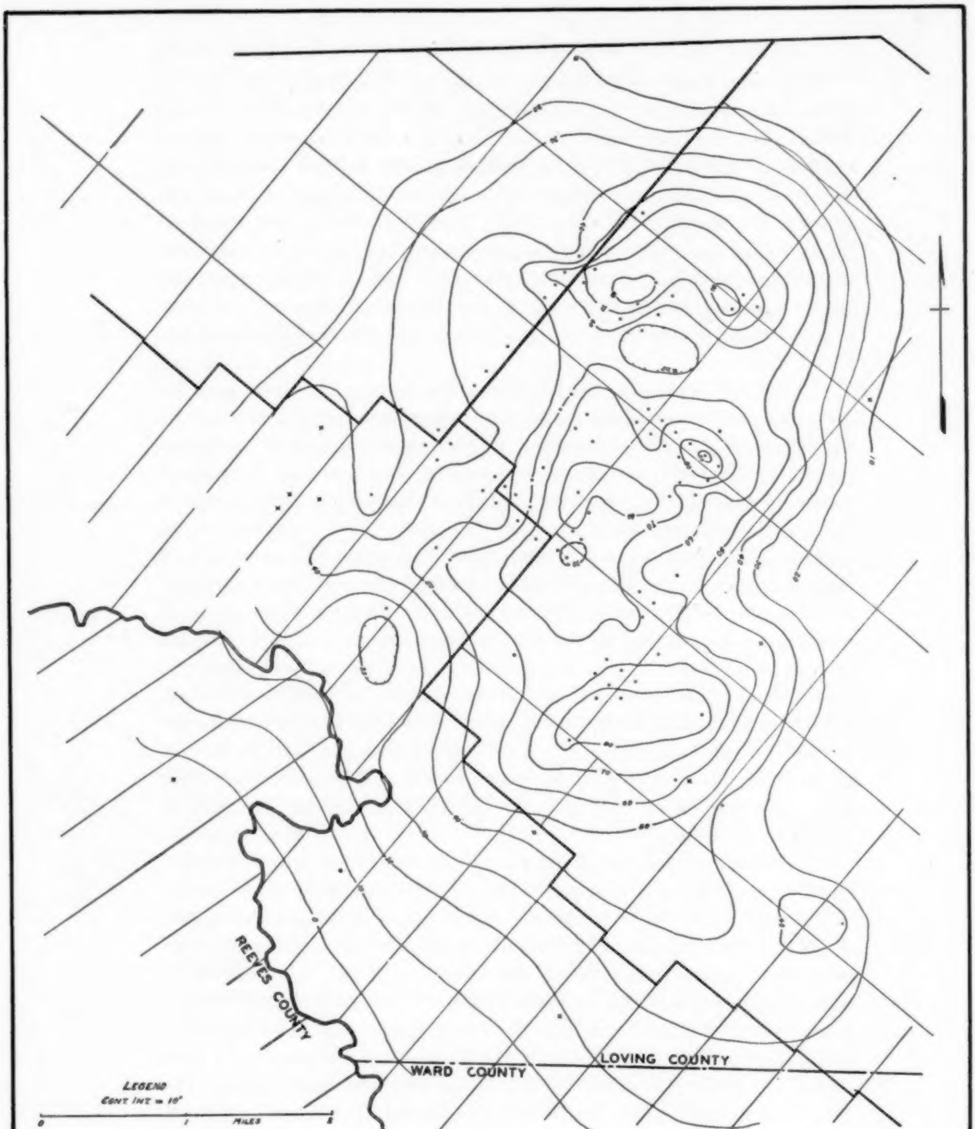

FIG. 5.—Isopach map of Wheat pool contoured on departure of present structure from normal dip of "Frijole" determined from surrounding wells.

strata shows that the floor of the basin sloped gently toward a central low and that no local fold existed until long after the close of "Frijole" sedimentation. The earliest possible period of movement with which the Wheat fold can be associated is the diastrophism that occurred between the deposition of the Upper Castile and the Rustler. Evidence for such dating is that several hundred feet of uppermost Upper Castile, present immediately on the east, are absent over the pool. Post-Permian solution which removed all the upper salt from the area on the west has so distorted the strata as to make it impossible to tell whether there was originally a corresponding off-structure thickening in that direction. The presence of oölites in the dolomite member of the Rustler over the pool and their absence in surrounding areas may indicate a local high and possibly a period of sub-aerial exposure during the Rustler deposition.[6] As further evidence, the Rustler itself, except for solution slumping already mentioned, has apparently been unaffected by any post-depositional folding in the immediate area. The local structure of the Wheat pool has apparently never been more than a minor fold of low relief.

Mountain building and regional rotation beginning late in the Permian and continuing through the Mesozoic into the Tertiary were responsible for tilting almost the entire area of the Delaware Basin into an eastward dipping homocline with a gradient of about 80 feet to the mile. As a result of this series of uplifts the western margin of the basin was raised more than 10,000 feet above the eastern rim and the axis of the basin was shifted eastward to the foot of the eastern reef.

The last and possibly the most important uplift of the series occurred in the Miocene. It was probably this late movement that raised the western edge of the Upper Castile salt into the zone of circulating ground waters, thus initiating the cycle of solution slumping and fill noted in the wells west of the Wheat pool.

At some time in the progress of regional rotation, the west edge of the low Wheat pool structure was raised sufficiently higher than the original crest to reverse the dip on the west flank of the fold, leaving the previously closed dome as an open terrace. Probably this reversal was associated with the Miocene uplifts.

Although the structure contours show no closure at the Wheat pool at the present time, the existence of local closure at some period in the past is disclosed by contouring the interval between the present position of the "Frijole" and the surface the "Frijole" would have

[6] A. A. L. Mathews, "Origin and Growth of the Salt Lake Oölites," *Jour. Geol.*, Vol. 38 (1930), pp. 633–42.

presented if no local folding was present and the normal regional dip extended across the entire area. The departure from normal is determined by superimposing contours representing the normal dip as determined from surrounding wells on the present structural contours. Accurate measures of divergence are available at the points of intersection, and these intervals, when contoured, show the original local structure of the area if, as assumed, the Wheat dome was the result of a single period of movement. Since the local structure is so slight, it was necessary to use 10-foot contour intervals. The dome as shown on Figure 5 was a somewhat irregular structure with a relief of somewhat less than 100 feet.

ORIGIN AND MIGRATION OF THE OIL

The Delaware Basin has the appearance of an ideal deep for the accumulation of organic material from which petroleum could be generated. The dark color of the "Frijole" beds and other dark shales of the Delaware Mountain section suggest an almost complete absence of oxidation, at least periodically during sedimentation. The fineness of the clastics also suggests a minimum of circulation. The probable depth of the water, as mentioned above, may have been as great as 2,400 feet.

No matter how favorable deep, poorly aerated basins may be for the accumulation of thanatocenose deposits, they are decidedly unhealthful for living organisms. Planktonic forms, which feed most of the other oceanic life, are most abundant in areas where upwelling cold water or cool polar currents[7] supply the necessary elements for life. Upwelling currents are caused by bottom irregularities. Populous zones may, therefore, have existed along the marginal reefs of the Delaware Basin, while the extremely regular areas near the center were almost lifeless. The limited quantity of oil in the Wheat pool may, therefore, be due to the paucity of organic material in the drainage area, as well as to the late development of the structure.

The catchment area of the Wheat pool, including as it apparently did only the area of local closure, was of limited extent. Presumably petroleum began to accumulate as soon as the trap was formed. The fact that any oil accumulated may be taken as evidence that all oil is not generated and driven out of the source beds by the time the cover reaches a thickness of approximately 1,000 feet, because at

[7] H. B. Bigelow, "Reports of the Scientific Results of the Expedition to the Eastern Tropical Pacific in Charge of A. Agassiz," *Mem. Mus. Comp. Zoöl. Harvard*, Vol. 37 (1909), p. 222.
R. C. Murphy, "Oceanography of the Peruvian Littoral with Reference to the Abundance and Distribution of Marine Life," *Geogr. Rev.*, Vol. 13 (1923), p. 79.

least 4,000 feet of bedded evaporites were laid down above the producing horizons before the first folding could have occurred. Of course, this thick series of sediments may have accumulated in a very short time, geologically speaking.

The uptilting of the western margin of the Wheat pool and the opening of the previously closed structure furnish further evidence of the slow migration of oil, even if, as is here assumed, the critical angle was not reached until the Miocene. Apparently the change of dip has caused the oil to begin shifting across the structure, as testified by the occurrence of commercial production a mile and a half up dip from the crest of the original dome and its extent only ½ mile down the over-steepened east flank.

A special series of events has been proposed to explain the original accumulation of the oil in the Wheat pool. The query is, why does the oil stay in the structure under present conditions? Explanatory hypotheses follow one or another of four main trends. The first and simplest answer is that petroleum originates in the place in which it is found, migrates little if any during geological time and, therefore, is to be expected at or very near the place where it was generated. This suggestion does not meet with general approval of many geologists, among whom in this instance is the writer. The main objection is probably the fact that in the case of non-migration there is no more reason for the oil to be present in the Wheat pool than at any other point in the Delaware Basin.

Those who follow the second trend believe that either a structural or lithologic trap exists in every pool and, therefore, must be present here. A fold or fault not discernible from well data may be present or a lateral change, from permeable to impervious sediments, not heretofore recognized, may have checked migration. The presence of a reverse fold is highly improbable. The lithology of the sediments is microscopically indistinguishable, the bedding as shown by cores is exceedingly uniform, and the presence of a hole full of fluid at every point where the reservoir is encountered discredits the possibility of tight areas. Faults may exist. A single fault or series of faults with a few inches or at most a few feet of throw could have left openings in the rock in which veins of calcite, gypsum, or silica developed. The absence of such veins in the cores and of vein material in the cuttings of the Delaware Mountain sand is an argument against this assumption, although admittedly it is not conclusive. The interference of established flow when new wells are completed is much more convincing evidence of free circulation.

Followers of the third hypothesis assume that migration has been

checked by a change in the physical or chemical character of the oil. Oxidation by surrounding waters may cause the marginal oil to become too viscous to flow through the fine sands under the present conditions of heat and pressure. The suggestion has some merit. The fact that some water is intimately mixed with all the oil in the reservoir and yet the oil flows readily into the wells does not disprove the assumption because the differential pressure existing at the bottom of a well is much greater than that in an untapped reservoir.

The outstanding objection to this theory is that if water action on oil is sufficiently violent to cause the oil to become too viscous to migrate up a slope as steep in some places as 80 feet to the mile, it is likely to be effective enough elsewhere to prevent any sort of migration.

Another possible physical change which may have hampered migration was the loss of the gas vehicle which assisted in the original accumulation. The pool is noted for its low gas-oil ratio. Practically no gas cap whatever is present. It may be assumed that gas and oil together worked their way into the reservoir where the gas accumulated in the crown of the structure. When the tilting took place the gas flowed up the dip as a big bubble and rapidly left the oil behind on an open terrace.

The fourth group of hypotheses explain non-migration by assuming that for every size grade of sand there is a critical angle of dip up which oil can migrate, and until this critical angle is reached no migration will occur. For sands of the fineness of those in the upper Delaware Mountain, the critical dip is about 60 feet to the mile, or about 10 feet per mile steeper than the average dip from one edge of production to the other.

CONCLUSIONS

From the arguments suggested above it is at once apparent that theories and hypotheses to account for the occurrence of commercial quantities of oil on open terraces, such as the Wheat pool, are as numerous as the birds of the air. Before any of them can be accepted as pertinent, they must explain certain conditions.

1. There is liquid, either oil or water, at the top of the Delaware Mountain sands in every well in and around the pool. Even the water wells, miles from the pool, usually show traces of oil.

2. The sands through which the oil would have migrated in escaping from the pool have the appearance, when examined microscopically, of being uniform in texture and cementation, and judging from the flow of oil and water, are uniformly permeable.

3. The oil has migrated up dip for a certain distance because the edge of production is found a mile and a half from the original crest on the up-dip flank and only a half mile from the crest on the other side.

DISCUSSION

W. B. Wilson, Tulsa, Oklahoma: In the Wheat pool, Mr. Adams has pointed out an interesting occurrence of oil in that available records indicate water is present, both up and down dip from the oil in the same reservoir. His conclusion that the oil is not able to move up dip through such fine sand seems warranted, and is the equivalent of saying that a lithologic closure is present in the up-dip direction. It does not follow that the oil accumulation is controlled by the structural terrace that is present, or that it would move on up the dip out of the area if the dip were to become steeper.

If the terrace is the controlling factor it would seem that the oil should have a more definite relation to it. In fact, the most striking flattening in the dip is on and near The California Company's Chapman lease. Although the field was open nearly a decade ago, development has not extended into this area, suggesting strongly to one not familiar with the details of the lease and production situation that the area is not worth drilling, due to unfavorable porosity conditions.

Mr. Adams' idea that the oil was able to move into the structure through the same sort of fine sand as now prevents further movement is worthy of consideration. Physicists are not in full accord, but the preponderance of available evidence favors the view that there is no minimum pressure that must be exceeded for migration to begin. Fineness of sand and gas content of oil merely affect resistance and therefore rate of flow.

If the facts are as set forth, it seems more reasonable to the present writer that local sources contributed chiefly to the oil in the Wheat pool and that it has been prevented from leaving by the fineness of the porosity of the reservoir, a condition that would continue effective regardless of the dip and the presence of the structural terrace. Moreover, if it were leaving at all, it is reasonable to consider that it would do so at a faster rate than a mile and a half in the several million years that must have elapsed since the Miocene tilting.

One other point is perhaps worthy of mention. Some geologists believe that after oil and water have been long in contact in a structure there is some chemical reaction that creates a barrier at their contact that may be no more than paper thin, but which would effectively prevent migration on elimination of structural closure, and which, likewise, prevents entrance of water into reservoirs as the oil is depleted. Such a barrier, if present, could naturally not be detected in well cuttings and possibly not even in cores. Moreover, Mr. Adams points out that cracks and fractures found in the wells are partially or entirely filled with calcite and that undiscovered faults, similarly filled, may exist, which would make a closure for the pool. Unfortunately any misgivings of this nature are not reflected in the title of his paper.

In summary, the Wheat pool has more of the appearance of being an accumulation of the open-reservoir type than any other that has been brought to my attention. That it is actually of this type and that the oil there is, in fact, controlled by the structural terrace that happens now to be present, is

by no means established. In the first paragraph of his paper Mr. Adams states that other pools are known in which open terraces are the only causative structures for retaining oil in place. If by "causative structures" he means that terraces are the controlling factor, I believe it would be of general interest to have further discussion of them.

Tulsa, Oklahoma
January 23, 1936

John Emery Adams: Mr. Wilson's discussion stresses a number of points brought out in the original paper which was written to show that under some, perhaps special, conditions reservoirs may be found in non-lensing sands where there is no closure in the producing zone and no apparent trapping agent.

If any of the causes of non-migration suggested by Mr. Wilson are effective agents, in this case, one would expect them to be operative in other areas where they should act as checks to prevent migration from established oil fields, under most conditions.

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SOURCE MATERIAL FOR PETROLEUM AND NATURAL GAS[1]

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ABSTRACT

One of the problems that confront the geologist is the source material for the pool accumulations of petroleum and natural gas. This paper deals with the findings, in Ohio, in limestones, dolomites, and calcareous shales, in a wide section from the Point Pleasant limestone in the Ordovician system to the Delaware limestone in the Devonian. These rocks were carefully sampled and analyzed, the results being representative of the materials throughout the section. Aside from the other components, the analyses give the content of carbon and hydrogen held in the organic paraffine compounds derived from the oily or fatty matter of the original animal life. From these determinations the total amount of natural petroleum per acre for that particular bed is calculated. The thickness of rocks thus covered is 1,160 feet. The results show a wide distribution of such matter and a low total quantity.

From analyses of a number of dolomites, limestones, and calcareous shales in Ohio an approximation is gained of the source material for petroleum and natural gas in some of the common rocks of the area. With the dense strata, such as hard dolomites and limestones and compact blue shales, the content of bituminous matter, as now determined, appears to represent about all of such organic compounds that were laid down with the original sediments. With the more open-textured dolomites and limestones the chances are much increased for migration and accumulation or for impoverishment or enrichment. The analyses indicate such changes. The concentration of bitumen may be in the capillaries of the rock, in cavernous openings, or in the cells of corals, sponges, et cetera. Porosity is certainly a basic factor in commercial production. Although the results, for the bituminous matter as determined by analyses, seem large, they are not excessive, but are in keeping with the yield of field production. The accumulations in the known pools certainly seem ample to account for any loss of such matter in the rocks or for that lost by natural distillation through the geological ages. The tests merely add some definite information on the content of the organic paraffine compounds in some of our common rocks.

The rocks tested for their hydrocarbon content range in age from the Point Pleasant limestone and shale of the Ordovician system to

[1] Manuscript received, February 24, 1936.

[2] State geologist, Geological Survey of Ohio.

the Delaware limestone of the Devonian. In general, the tests are representative of the carbonate rocks in the Ordovician, Silurian, and Devonian systems. The samples were cut by the writer or by R. E. Lamborn, assistant geologist of the Geological Survey of Ohio, to determine their value for industrial purposes. They were cut continuously across the face of the exposure, usually a quarry or road cut with fresh material. The field samples, averaging about 100 pounds, were then repeatedly crushed and quartered, to the size of laboratory samples, which were used for the determinations. In general, samples of each formation were cut over a rather wide area and in various parts of the section. The proportion of sample to total rock thickness was least in the Cincinnati group, but this is not a serious discrepancy, as these rocks throughout are similar in composition and texture. The samples were carefully analyzed by a skilled chemist and each determination checked. The Hillebrand and Lindgren method for rock analysis was used. The carbon and hydrogen as determined represent all of such matter in the rocks, as such compounds are from the oily and fatty tissues of animal life and not from vegetable spores. The writer feels that the samples are truly representative of the rocks examined. They represent a wide range of composition and serve as exhibits of such rocks in general.

The organic paraffine compounds, extracted by dissolving away the rock, and then checked through solution in ether, were analyzed for carbon and hydrogen. The results in all cases show that the quantities of these elements approach closely the hydrocarbon C_nH_{2n+2} or that of the paraffine series to which both petroleum and natural gas belong. The ratio of carbon to hydrogen is remarkably constant, indicating a uniformity of composition. The results are expressed in per cent by weight. As thus found in thirty determinations, the quantity of bituminous matter present in the carbonate rocks varies from .06 per cent in a dense limestone to 1.84 per cent in an open-textured dolomite, well saturated with tarry substances. The average content is .4785 per cent and the total thickness of rocks thus included is 1,160 feet.

The results of the investigation tend to show that the carbonate rocks hold large but not excessive quantities of paraffine compounds yielding petroleum and natural gas, that such source material is readily available for any distillation processes initiated by nature, that migration over long distances is not necessary for accumulation, and that the amount drained to pools represents only a small part of the whole.

Accumulation depends on many factors, one of which is the texture of the rock itself. In the dense dolomites, limestones, and shales the organic compounds are so diffused and so tightly sealed by the rock particles that they are retained with great tenacity and thus contribute little to any accumulation of petroleum or natural gas. In such materials the contents of carbon and hydrogen are relatively high, indicating that little has been lost through the geological ages. Furthermore, in such strata the wide migration of oil or gas is not possible and no reservoirs are present to receive contributions. In the more open-textured rocks the conditions are different. The oil and gas found in them, however, represent the small and incidental fractions produced through several factors, all operating favorably, rather than results of any general process of widespread regionality. The residue in the strata is far greater than the part extracted.

Such hydrocarbons were derived from the oily or fatty parts of the animals and plants, mainly the former, that lived in the sea and that, on dying and passing through putrefaction in marine waters, left bituminous substances, in some cases, along with skeletal matter, as a part of rock contribution. This bitumen is dark in color, viscous in character, and pitch-like in odor. It is made up, through solubility of one component in another, of many compounds varying in properties from the more solid waxes, through the light volatile oils, to the true gases. In constitution these rock hydrocarbons are close to those of the natural heavy petroleums and on breaking down yield products for reservoir accumulation.

The rock formations thus examined are as follows.

	Thickness in Feet
Devonian system	
Delaware formation, siliceous limestone	45
Silurian system	
Niagara formation, dolomite, pure to siliceous	110
Ordovician system	
Richmond formation, dense shale and limestone	385
Maysville formation, dense shale and limestone	270
Eden formation, mainly dense shale	280
Cynthiana, Point Pleasant formation, dense limestone and shale	70
Total	1,160

DELAWARE FORMATION

The Delaware formation was sampled in eight places in Franklin, Delaware, Marion, Seneca, and Erie counties. A representative analysis follows (analyst, Downs Schaaf).

	Per Cent by Weight
Silica, SiO_2	9.25
Alumina, Al_2O_3	1.60
Ferric oxide, Fe_2O_3	.59
Ferrous oxide, FeO	.33
Pyrite, FeS_2	.28
Magnesium oxide, MgO	6.40
Calcium oxide, CaO	40.89
Strontium oxide, SrO	None
Sodium oxide, Na_2O	.07
Potassium oxide, K_2O	.08
Water, hydroscopic, H_2O-	.38
Water, combined, H_2O+	.42
Carbon dioxide, CO_2	38.92
Titanic oxide, TiO_2	.09
Phosphorous pentoxide, P_2O_5	.22
Sulphur trioxide, SO_3	.05
Manganous oxide, MnO	.06
Vanadium oxide, V_2O_5	$<.01$
Barium oxide, BaO	$<.01$
Carbon, organic, C	.59
Hydrogen, organic, H	.08

Listing only the carbon and hydrogen the results on the eight samples are as follows (analyst, Downs Schaaf).

Sample Number		Thickness of Sample Feet	Inches	Carbon	Hydrogen	Total
22	Limestone, shaly, dark	15	8	.95	.14	1.09
21	Limestone, siliceous, dark	22	9	.63	.09	.72
19	Limestone, siliceous, dark	23	10	.59	.08	.67
15	Limestone, siliceous, dark	25	2	.44	.05	.49
18	Limestone, siliceous, dark	12	9	.56	.08	.64
16	Limestone, siliceous, dark	20	8	.60	.08	.68
17	Limestone, siliceous, dark	5	10	.68	.07	.75
20	Limestone, siliceous, dark	34	6	.62	.08	.70
			Total	5.07	.67	5.74
			Average	.63+	.08+	.72−

In considering the problem of the natural paraffine compounds per acre the following figures are used.

Thickness of rock, 45 feet
Weight of cubic foot of stone, 168 pounds
Weight of cubic foot of bitumen, 57 pounds
Quantity by weight of bitumen in rock, .72 per cent
Number of square feet per acre, 43,560
Number of cubic inches per cubic foot, 1,728
Number of cubic inches per gallon, 231
Number of gallons per barrel of oil, 42

$$\frac{45\times168\times72\times43{,}560\times1{,}728}{57\times10{,}000\times231\times42} = 7{,}409 \text{ barrels.}$$

From the above, the entire concentration in the 45 feet of Delaware limestone would provide at best only a small oil well, yielding

about 2 barrels per day for 10 years. Even a small pool would require concentration from a rather large area.

NIAGARA GROUP

The Niagara group consists mainly of dolomites, many of which are pure. In some members considerable bitumen is apparent in cells of corals and in the cavernous openings in the rock itself. In one area the rock is sticky with the organic matter, representing an old dried-up oil pool. The following analysis is representative of the high-grade dolomites (analyst, Downs Schaaf).

	Per Cent by Weight
Silica, SiO_2	.24
Alumina, Al_2O_3	.11
Ferric oxide, Fe_2O_3	.21
Ferrous oxide, FeO	.20
Pyrite, FeS_2	<.01
Magnesium oxide, MgO	21.40
Calcium oxide, CaO	30.18
Strontium oxide, SrO	None
Sodium oxide, Na_2O	<.01
Potassium oxide, K_2O	<.01
Water, hydroscopic, H_2O-	.14
Water, combined, H_2O+	.06
Carbon dioxide, CO_2	47.34
Titanium oxide, TiO_2	.006
Phosphorous pentoxide, P_2O_5	.02
Sulphur trioxide, SO_3	None
Manganous oxide, MnO	.01
Vanadium oxide, V_2O_5	<.01
Barium oxide, BaO	None
Zinc oxide, ZnO	<.01
Carbon, organic, C	.36
Hydrogen, organic, H	.04

When only the carbon and the hydrogen are considered, the results in the Niagara group are as follows (analyst, Downs Schaaf).

Sample Number		*Thickness of Sample Feet*	*Inches*	*Carbon*	*Hydrogen*	*Total*
4	Dolomite, very pure, Peebles	34	0	.33	.04	.37
5	Dolomite, very pure, Peebles	22	0	.36	.04	.40
1	Dolomite, very pure, Peebles	23	0	.40	.05	.45
6	Dolomite, very pure, Peebles	32	0	.10	.015	.115
14	Dolomite, bituminous, Peebles	30	0	1.27	.22	1.49
14a*	Dolomite, bituminous, Peebles same pit	6	0	1.61	.23	1.84
13	Dolomite, impure, Lilly member	16	0	.08	.01	.09
2	Dolomite, impure, Lilly member	21	0	.25	.04	.29
10	Dolomite, impure, Lilly member	28	0	.24	.04	.28
8	Dolomite, impure, Lilly member	16	0	.41	.06	.47
9	Dolomite, impure, Bisher member	17	0	.25	.03	.28
3	Dolomite, impure, West Union	30	0	.25	.04	.29
11	Dolomite, impure, West Union	24	0	.38	.05	.43
			Total	4.32	.635	4.955
			Average	.36	.053	.413

* Sample No. 14a is from the same pit as No. 14, but was selected for its high content of bituminous or tarry matter, and therefore is not considered in the average given above.

As the Niagara group is 110 feet or more in thickness, the total organic paraffine in barrels per acre is as follows.

$$\frac{110 \times 168 \times 413 \times 43{,}560 \times 1{,}728}{57 \times 100{,}000 \times 231 \times 42} = 10{,}388 \text{ barrels.}$$

The total yield is thus not large and the original content was possibly not greatly in excess of that now present. These dolomites, however, are sufficiently open in texture for migration of both oil and gas. Since little accumulation is now present in any part of the Niagara group it seems evident that if oil or gas were generated in these strata through past ages, most of it was lost through escape to the surface or through migration to other formations. It is more probable that these rocks have never been the source of any heavy yield.

Sample No. 14a is worthy of some attention. The rock in this case represents that in an old oil pool which by uplift and erosion was brought to the surface, so that it is now quarried for road metal. In the quarry, 8 feet of this dolomite is thoroughly saturated with black oily petroliferous matter. The content of organic paraffine is 1.84 per cent. What is there now evidently represents the original bituminous matter from which some volatile compounds have escaped. Saturated as it is, the yield per acre is low, the results being as follows.

$$\frac{8 \times 168 \times 184 \times 43{,}560 \times 1{,}728}{57 \times 10{,}000 \times 231 \times 42} = 3{,}366 \text{ barrels}$$

CINCINNATI GROUP OF ORDOVICIAN ROCKS

The rocks in the Cincinnati group—Richmond, Maysville, Eden, and Cynthiana—consist of dense, bluish gray calcareous shales with dense, hard, dark gray limestones from 1 inch to 1 foot in thickness. In general the deposits are made up of about 35 per cent limestone and 65 per cent shale. The total thickness of rocks represented by the analyses is approximately 1,005 feet. Of this, 352 feet may be considered limestone and 653 feet shale. Representative analyses of these limestones and shales are given below (analyst, Downs Schaaf).

	Limestone Maysville	*Shale Eden*
Silica, SiO_2	6.50	45.50
Alumina, Al_2O_3	1.50	14.02
Ferric oxide, Fe_2O_3	.24	1.90
Ferrous oxide, FeO	.97	3.38

	Limestone Maysville	*Shale Eden*
Pyrite, FeS_2	.15	1.61
Magnesium oxide, MgO	1.20	2.95
Calcium oxide, CaO	48.65	9.80
Strontium oxide, SrO	None	None
Sodium oxide, Na_2O	.10	.65
Potassium oxide, K_2O	.15	3.75
Water, hydroscopic, H_2O-	.25	1.27
Water, combined, H_2O+	.41	3.74
Carbon dioxide, CO_2	39.27	9.90
Titanium oxide, TiO_2	.10	.88
Phosphorous pentoxide, P_2O_5	.55	.44
Sulphur trioxide, SO_3	.04	.14
Manganous oxide, MnO	.12	.11
Vanadium oxide, V_2O_5	<.01	<.01
Barium oxide, BaO	<.01	<.01
Carbon, organic, C	.08	.28
Hydrogen, organic, H	.01	.04

The organic contents in the samples of limestone and in the four samples of shale are as follows (analyst, Downs Schaaf).

Sample Number		*Thickness of Sample Feet*	*Inches*	*Carbon*	*Hydrogen*	*Total*
29	Richmond, dense limestone	23	6	.05	.01	.06
27	Maysville, dense limestone	5	3	.08	.01	.09
30	Maysville, dense limestone	9	5	.18	.03	.21
25	Eden, dense limestone	6	2	.07	.01	.08
23	Pt. Pleasant, dense limestone	11	5	.12	.02	.14
			Total	.50	.08	.58
			Average	.10	.016	.12
28	Maysville, dense shale	7	3	.25	.04	.29
31	Maysville, dense shale	13	1	.25	.04	.29
26	Eden, dense shale	11	9	.28	.04	.32
24	Pt. Pleasant, dense shale	2	7	.30	.05	.35
			Total	1.08	.17	1.25
			Average	.27	.04	.31

$$\text{Limestone} = \frac{352 \times 168 \times 12 \times 43{,}560 \times 1{,}728}{57 \times 10{,}000 \times 231 \times 42} = 9{,}659 \text{ barrels.}$$

$$\text{Shale} = \frac{653 \times 168 \times 31 \times 43{,}560 \times 1{,}728}{57 \times 10{,}000 \times 231 \times 42} = 46{,}289 \text{ barrels.}$$

The total of 9,659+46,289=55,948 barrels per acre for the Cincinnati group of 1,005 feet in thickness.

Such a study is very incomplete and faulty, but is indicative of some properties of the dolomites, limestones, and calcareous shales found in Ohio. The data suggest that source material is present everywhere throughout a great thickness of carbonate rocks in this state, ranging in age from Middle Ordovician to Middle Devonian; that the content of organic matter approaches closely the general paraffine formula, C_nH_{2n+2}; that the quantity incorporated is commonly not large; and that, in general, more organic matter is present in the dense rocks than in the open-textured ones. The known accumulations appear to be ample to meet any loss of such matter in the associated rocks.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 20, NO. 6 (JUNE, 1936), PP. 805-809, 1 FIG.

AGE OF MISSISSIPPIAN "RIDGETOP SHALE" OF CENTRAL TENNESSEE[1]

CHARLES W. WILSON, JR.,[2] AND E. L. SPAIN, JR.[3]
Nashville and Knoxville, Tennessee

ABSTRACT

Faunal and stratigraphic studies show the "Ridgetop shale" to be a phase of the New Providence shale, and to be of Fern Glen, rather than Kinderhook, age, as previously assigned.

ACKNOWLEDGMENTS

This work was sponsored by the Tennessee Valley Authority, and the writers wish to thank E. C. Eckel, chief geologist. L. C. Glenn read the manuscript and offered helpful suggestions. D. K. Gregor kindly checked the senior writer's identifications of many of the fossils collected from the New Providence shale.

INTRODUCTION

In 1912, Bassler[4] published the results of his study of the early Mississippian rocks of central Tennessee. In this report the strata between the overlying Fort Payne chert and the underlying Maury shale member of the Chattanooga shale were divided into two formations. The upper of these was correlated with the New Providence shale of Indiana, Ohio, and Kentucky, the local type section being at Whites Creek Springs, Davidson County, Tennessee. The lower formation was named the Ridgetop shale from its occurrence along the tracks of the L. & N. R. R. between Ridgetop, Robertson County, and Bakers Station, Davidson County, Tennessee. This formation was correlated with parts of the Kinderbook group of the Upper Mississippi Valley.

The present writers accept the local use of New Providence, but believe the strata designated as Ridgetop are only a phase of the New Providence and are similarly of Fern Glen, not Kinderhook, age.

Evidence given for the setting apart of the "Ridgetop shale" may be summarized as follows.

[1] Manuscript received, January 31, 1936. Published with the permission of the chief geologist, Tennessee Valley Authority.

[2] Department of Geology, Vanderbilt University.

[3] Tennessee Valley Authority. Both authors introduced by L. C. Glenn.

[4] R. S. Bassler, "The Waverlyan Period of Tennessee," *Proc. U. S. Nat. Museum*, Vol. 41 (1912), pp. 209–24.

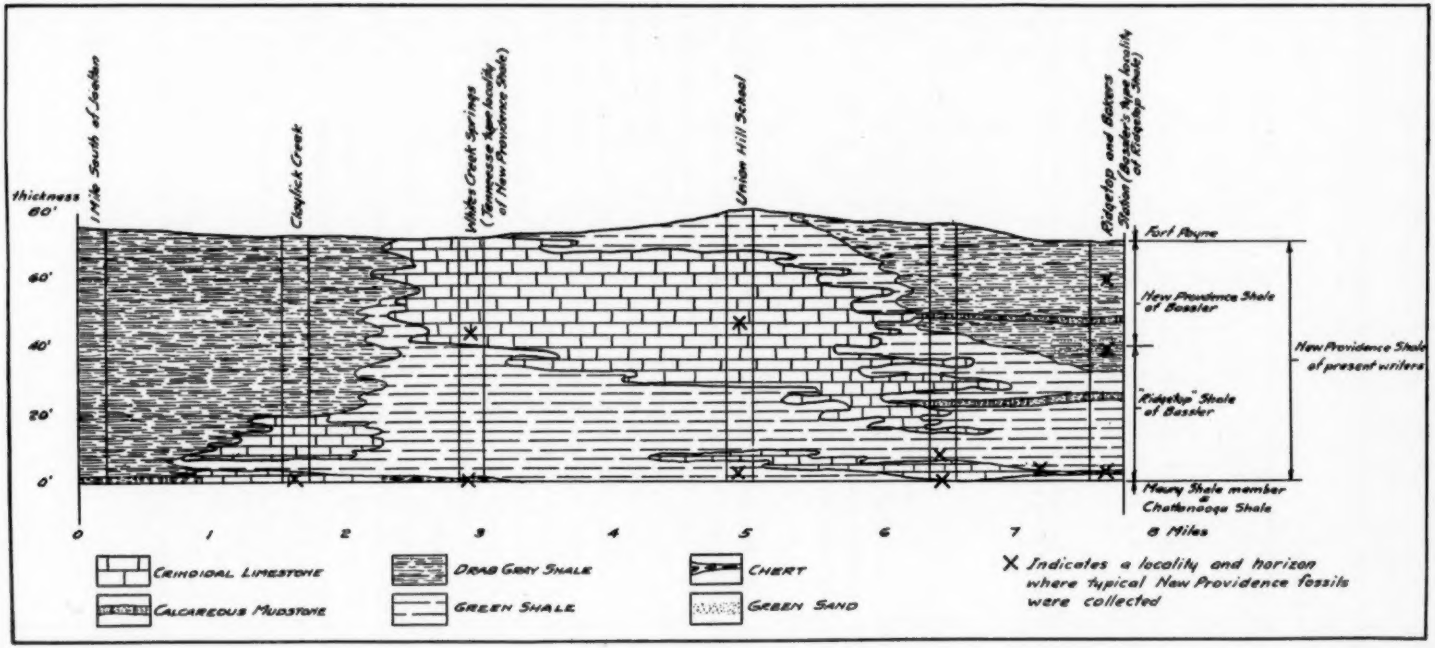

FIG. 1.—Detail cross section of New Providence shale from Ridgetop and Bakers Station (type locality of "Ridgetop shale") southward to Whites Creek Springs (local type section of New Providence) and beyond to Joelton, showing intergradation of different facies of formation. Localities at which careful measurements were made are indicated.

1. A faunal list of 13 species published in 1869 by Winchell which was collected from shales just above the Chattanooga shale in Hickman County, Tennessee, and the adjoining edge of Maury County, Tennessee. Four of these identifications were queried by Winchell, and three were new species having no correlative value at that time. This faunal list was published in Safford's *Geology of Tennessee.*

2. An ostracod, *Ctenobolbina loculata* Ulrich, which is also found in the Louisiana limestone (Kinderhook) of Missouri.

3. In 1932[5] three additional species were listed from the "Ridgetop shale." These species are *Chonetes ornatus*, *Rhipidomella diminutiva*, and *Cyrtina burlingtonensis*, all three of which occur in the Kinderhook, but the latter two also occur in the Fern Glen.

There is an almost complete lack of definite criteria, either faunal or stratigraphic, for the differentiation of the "Ridgetop shale" from the New Providence shale. Also, this interpretation requires the acceptance of surprisingly rapid reversals of lithology and color; marked changes in thickness; and unusual replacements of one by the other of the "Ridgetop" and the New Providence in a region where such rapid changes are not otherwise known. As examples of the latter are the exchange of 200 feet of "Ridgetop shale" in the eastern part of the Lillydale Quadrangle, Tennessee, where the New Providence shale is absent, for 200 feet of New Providence shale in the western part of the quadrangle, the "Ridgetop" being absent. Also, there is the change of 30 feet of New Providence and 50 feet of "Ridgetop" at the type locality of the latter for 200 feet of "Ridgetop shale" only 2½ miles east. Another change similar to these is shown in Bassler's identification of the "Ridgetop shale" at Ridgetop and Bakers Station, as shown in Figure 1.

STRATIGRAPHIC WORK

The present writers have traced different units of the New Providence shale from its local type locality, Whites Creek Springs, and of the "Ridgetop shale" from its type locality, only 5 miles away, and find that they intergrade. Crinoidal limestone lenses and fossiliferous shale with typical assemblages of New Providence fossils occur immediately above the Maury shale member of the Chattanooga shale in what was previously considered to be the base of the "Ridgetop shale," only ¼ mile from the type locality (Fig. 1). Also, at the base of the "Ridgetop shale" along the tracks between Bakers Station and Ridgetop, a New Providence fauna was collected from a thin chert layer at the base of the shale.

[5] R. S. Bassler, "Stratigraphy of the Central Basin, Tennessee," *Tennessee Div. of Geology Bull. 38* (1932).

The strata between the Fort Payne chert and the Maury shale member of the Chattanooga shale in the area of Ridgetop and Whites Creek Springs are shown in Figure 1 to be represented by four intergrading facies, crinoidal limestone, drab gray shale, calcareous mudstone, and green shale. As shown in this figure the "Ridgetop shale," separated at Bakers Station and Ridgetop by Bassler, grades into New Providence shale and crinoidal limestone.

Along the railroad near Iron City in eastern Wayne County, Tennessee, there occurs more than 100 feet of New Providence shale and limestone. The lithology of both the limestone and shale is quite similar to that of the New Providence in the vicinity of Whites Creek Springs.

The shale is thin bedded, soft, and is dark green in color. It is crowded with typical New Providence bryozoans and at various horizons carries other diagnostic fossils. Lenses of greenish, coarsely crystalline crinoidal limestone occur at several points in the extensive shale outcrop, reaching a maximum thickness of 50 feet behind the Iron City R. R. Station and a quarter of a mile west of the station on a spur track. The lithology of these exposures in the vicinity of Iron City and the faunal remains studied clearly demonstrate the New Providence age of the formation.

As these typical New Providence beds are traced to the west, they interfinger very definitely with the dark "Ridgetop shale" phase which has been recognized in the southern part of the Western Highland Rim by Miser[6] and Jewell[7] who had accepted the then existing determination of a Ridgetop formation. It appears from this evidence that the "Ridgetop" as there recognized is a lithologic type of the New Providence shale.

PALEONTOLOGIC WORK

The following are faunal lists of fossils collected from the "Ridgetop shale." These fossils were identified by the senior writer, and were checked in part by D. K. Gregor.

1. FROM CHERT LAYER AT BASE OF "RIDGETOP SHALE" AT BAKERS STATION

Zaphrentis wortheni
Amplexus rugosus
Beaumontia americana
Cladochonus americanus

Productus burlingtonensis
Echinoconchus alternatus

[6] H. D. Miser, "Mineral Resources of the Waynesboro Quadrangle, Tennessee," *State Geol. Survey Bull. 26* (1921).

[7] W. B. Jewell, "Geology and Mineral Resources of Hardin County, Tennessee," *Tennessee Div. of Geology Bull. 37* (1931).

Athyris hannibalensis
Reticularia pseudolineata
Cliothyridina obmaxima
Brachythyris suborbicularis

Cystodictya lineata
Rhombopora incrassata
Fenestella regalis

Platyceras paralius

Phlippsia sp. (unidentified, but the same species that occurs so abundantly in the New Providence shale at Ridgetop)

2. FROM GREENSAND LAYER AT BASE OF "RIDGETOP SHALE" ½ MILE SOUTH OF BAKERS STATION

Spirifer mortananus
Brachythyris suborbicularis

3. FROM "RIDGETOP SHALE" 7 MILES NORTH OF WHITE BLUFF, DICKSON COUNTY

Hadrophyllum tennesseensis

Chonetes shumardanus
Chonetes multicosta
Linoproductus ovatus
Avonia blairi
Brachythyris chouteauensis
Reticularia pseudolineata

Of these 22 species 21 commonly occur in Fern Glen or younger beds, 3 are known to occur in Kinderhook, Fern Glen, and younger beds—but only one is typically Kinderhook.

CONCLUSIONS

From the stratigraphic and paleontologic evidence, the present writers believe that the "Ridgetop shale" is not a separate formation and that strata previously assigned to the "Ridgetop" are only a phase of the New Providence. If beds of Kinderhook age (other than probably the Chattanooga shale) are present in central Tennessee, they are not represented in the beds formerly separated as the "Ridgetop shale." The "Ridgetop shale" has been postulated as occurring in embayments on the northern and western flanks of the Nashville dome island. Accepting the "Ridgetop" as a phase of the New Providence eliminates the theory of such embayments of deposition.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 20, NO. 6 (JUNE, 1936), PP. 810-815, 1 FIG.

PRICE OF CRUDE OIL IN PERSPECTIVE[1]

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ABSTRACT

The price of crude oil is reviewed in perspective from the inception of the American petroleum industry to the present by means of a comparison between the weighted average price of crude oil and the average price of thirty basic commodities. This stretch of oil prices is shown to divide itself into five distinctive periods, each related to some economic feature that influenced the nature of the price structure at the time.

GENERAL STATEMENT

We are so accustomed to dealing with the price of crude oil in its variations from place to place and during short periods of time that its relative and long-term movements are likely to be overlooked. It may be of interest, therefore, to view in perspective the broad sweep of the crude-oil price structure since the inception of the American petroleum industry. For this purpose it is necessary to eliminate detail and condense the data into a single average, such as the weighted average price of crude petroleum in the United States published by the United States Bureau of Mines. This series by years from 1859 to 1935 is given in Table 1.

TABLE I

WEIGHTED AVERAGE PRICE OF CRUDE PETROLEUM IN THE UNITED STATES BY YEARS, 1859–1935. DATA FROM U. S. BUREAU OF MINES
(In Dollars per Barrel)

1859	16.00		
1860	9.59		
1861	0.49	1901	0.96
1862	1.05	1902	0.80
1863	3.15	1903	0.94
1864	8.06	1904	0.86
1865	6.59	1905	0.62
1866	3.74	1906	0.73
1867	2.41	1907	0.72
1868	3.62	1908	0.72
1869	5.64	1909	0.70
1870	3.86	1910	0.61
1871	4.34	1911	0.61
1872	3.64	1912	0.74

[1] Read before the Association at Tulsa, March 19, 1936. Manuscript received, March 1, 1936.

[2] Consulting engineer, 29 Washington Square.

1873	1.83	1913	0.95
1874	1.17	1914	0.81
1875	1.35	1915	0.64
1876	2.52	1916	1.10
1877	2.38	1917	1.56
1878	1.17	1918	1.98
1879	0.86	1919	2.01
1880	0.94	1920	3.07
1881	0.92	1921	1.73
1882	0.78	1922	1.61
1883	1.10	1923	1.34
1884	0.85	1924	1.43
1885	0.88	1925	1.68
1886	0.71	1926	1.88
1887	0.67	1927	1.30
1888	0.65	1928	1.17
1889	0.77	1929	1.27
1890	0.77	1930	1.19
1891	0.56	1931	0.65
1892	0.51	1932	0.87
1893	0.60	1933	0.67
1894	0.72	1934	1.00
1895	1.09	1935	0.98*
1896	0.96		
1897	0.68		
1898	0.80		
1899	1.13		
1900	1.19		

* Estimated

THE PRICE RECORD

Figure 1 shows by years, from 1860 to 1935, the weighted average price of crude oil in the United States compared with the price of thirty basic commodities (Warren-Pearson Index). Both series are expressed as index numbers, with the five-year pre-war period of 1910–1914 taken as a base of 100. The actual price corresponding to the crude-oil index is also entered on the scale at the right, so that the price in dollars per barrel can be interpolated. A study of this chart reveals two important features: (a) the price of crude oil tends to conform in its broad movements to the prices of other basic commodities; and (b) the price history of crude petroleum has been written in five chapters, each influenced by a dominant development in the industry.

RELATION TO BASIC-COMMODITY INDEX

The correlation between the price of crude oil and the price of thirty basic commodities is general rather than specific. The crude-oil curve has much greater amplitude of movement than the commodity

curve, but this is due in part to the comparison of a single average with a composite average in which the individual aberrations tend to be ironed out. Also for short periods of a year or more the two curves not infrequently diverge. Nevertheless, the exhibit indicates that, broadly speaking, the price of crude petroleum is strongly influenced by the same underlying economic forces that affect other commodities.

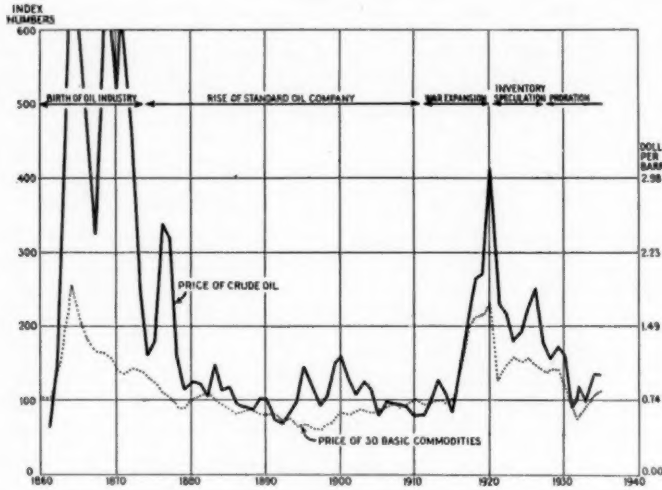

FIG. 1.—Weighted average price of crude oil in the United States compared with price of 30 basic commodities by years, 1860–1935 (1910–1914 = 100).

This generalization is important because we are prone to look upon the price of crude oil as an isolated phenomenon having only a remote connection with the general level of prices. It may be observed that each time the crude-oil index rose above the commodity index, the lapse of time witnessed its return to the general level. Thus, while the price of crude oil may be determined for short periods by conditions peculiar to the oil business, it is responsive in the long run to those forces that dominate our economy. Circumstances within the oil business affect primarily the supply side of the supply-demand equation, while general conditions control the demand side of the equation.

FIVE CHAPTERS IN THE HISTORY OF CRUDE-OIL PRICES

A close study of Figure 1 will reveal five important phases of the price history of crude petroleum, which may be tabulated as follows.

Phase	Period	Length (Years)	Price (In Dollars per Barrel) Average	Range	Dominant Feature
1	1859–1877	19	4.28	0.49–16.00	Birth of industry
2	1878–1915	38	0.81	0.51– 1.19	Rise of Standard Oil Co.
3	1916–1920	5	1.94	1.10– 3.07	War expansion
4	1921–1926	6	1.61	1.34– 1.88	Inventory speculation
5	1927–1935	9	1.01	0.65– 1.30	Proration

The earliest period, 19 years in length, covers the formative stage of the petroleum industry, and was marked by extremes of price fluctuations. In the fore part of this cycle, prices varied up to several hundred per cent from one year to the next, but a tendency toward stabilization at lower levels appeared as the industry progressed toward an established status. This period corresponds with the commodity price inflation brought about by the Civil War and with the deflation following that disturbance.

The second phase of oil prices made its appearance at about the three-quarter mark of the past century and lasted until the outbreak of the World War. This period was 38 years in length and was characterized by considerable price stability, relatively low average levels, and, broadly viewed, a horizontal trend. The weighted average price of crude oil during this time was 81 cents per barrel. This phase represented a "normal" period between the inflation of prices accompanying the Civil War and the price inflation generated by the World War. During this period, a significant feature of the petroleum industry was the rise of the Standard Oil Company to a dominant position and its dissolution by court decree in 1911. The structure of the industry during this entire term was one of non-integration as between crude-oil production, on the one hand, and the transportation-refining-marketing activities, on the other. There was thus a discontinuity between the function of producing crude oil and the rest of the industry. This era largely antedated the important use of gasoline as motor fuel.

The third price cycle under review was a short one, only 5 years in length, extending from 1916 to 1920. It coincided with the rise of war demands, credit financing, and inflation of commodity prices that accompanied and followed the World War. The weighted average price of crude oil rose from 64 cents a barrel in 1915 to $3.07 per barrel in 1920. This term was also marked by the development of considerable integration between crude-oil production and the other departments of the industry. The tendency of demand to run ahead of supply gave rise to the "shortage concept" which has influenced the industry at intervals ever since. The profits generated by the rise in

prices brought the industry for the first time into the money markets for new capital on a large scale and set in motion an inflow of new capital that was responsible for much of the overproduction that ensued later on. A renewed inspection of Figure 1 will emphasize the wholly abnormal character of the oil price structure during this inflation phase.

The years 1921–1926 covered a time of price deflation representing a reaction to the abnormal rise that preceded, and witnessed the development of resistance to the deflationary reflex. With production stimulated by the preceding high prices, overproduction developed and for several years the industry contended with a surplus supply. As the shortage concept was carried over from the previous era, the surplus was willingly stored as a speculation on the theory that the overproduction was an interlude to be followed by renewed scarcity and rising prices. The downward price tendency was accordingly arrested for a time and even temporarily reversed, but at the expense of a vast accumulation of crude oil in storage. The oil price structure was accordingly influenced for a term of five or six years by inventory speculation, a procedure that inflated demand to the extent of the quantity stored but at the same time set up a claim on future demand that subsequently had to be liquidated.

The fifth phase in the development of the crude-oil price structure was the logical outgrowth of the third and fourth cycles previously reviewed. The stimulus of war prices, working through the responsive medium of advancing technology, created a momentum that the spectacular rise in gasoline consumption was unable to absorb: a momentum too great, also, to be offset by the expedient of inventory accumulation. Proration, accordingly, evolved as an instrumentality for holding the unwanted oil in underground storage; but this device was unable to halt the fixation of capital in the new reserves; consequently, an expanding crude-oil "potential" was built up which eventually, when demand turned downward during the depression, led to a return of crude-oil prices to the pre-war level. For the three-year period, 1931–1933, the weighted average price of crude oil was 73 cents per barrel, or slightly below the pre-war average. Then came the petroleum code and the stabilization of crude-oil prices at a dollar base, which continued, with some local interruption, into January of 1936, when the base price (36° Mid-Continent crude) was advanced 10 cents per barrel.

The period of proration is complicated by its position covering the later phases of the credit inflation of the twenties, the drastic deflation resulting therefrom, and the early stages of recovery starting in 1932.

These dominating phases of our economy were important influences on the effect exercised by proration upon crude-oil prices, modifying the stabilizing results that proration was expected to bring about. In the latest phase, the sharp rise in oil demands that has recently accompanied the recovery movement has played a dominant rôle in strengthening the oil price structure.

PRICE A CAUSE AS WELL AS AN EFFECT

This brief review of the price history of crude petroleum and the main external forces that have affected it would not be complete without calling attention to the fact that price responds naturally to no force unless it alters either supply or demand. Price, however, is more than a response to supply and demand; it, in turn, influences supply and demand. Price, therefore, is both a cause and an effect; and its causal rôle is often overlooked. In the presence of competition, price, in its causal rôle, exercises four functions.

1. Price tends to equate supply and demand. 2. Price tends to integrate supply and demand, adjusting the component parts of one to the other. 3. Price tends to regulate the inflow and outflow of capital, the fundamental control of supply. 4. Price tends to repel or attract the fund of general purchasing power, the fundamental control of demand.

Under proration, price is relieved of the first mentioned function to a large extent, and partly so in respect to the second. But the effect of price upon capital movements and purchasing power is not altered by proration. Therefore, under proration, the innate price response to an artificial balance between supply and demand is limited and whenever price is forced above its critical point the result is valorization which is disruptive of equilibrium and can not be sustained. The future of crude-oil prices, with proration operative, will probably depend to a considerable degree upon the position of this critical level.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 20, NO. 6 (JUNE, 1936), PP. 816-818, 1 FIG.

GEOLOGICAL NOTES

NOMOGRAPHIC SOLUTION FOR APPARENT DIP IN VERTICAL SECTION NOT PERPENDICULAR TO STRIKE

In constructing vertical geologic sections along lines which are not perpendicular to the strike, it is evident that the apparent dip in the vertical section will be less than the true dip of the beds in a section perpendicular to the strike. Many solutions to the problem of obtaining the apparent dip from the true dip and the angle between the strike and the line of section have been obtained. One of these is described by Stanley C. Herold in the June, 1933, issue of this *Bulletin*. He arrives at the solution

$$\log \tan \alpha = \log \tan \theta + \log \sin \phi$$

where α is the apparent dip in the section, θ is the total dip and ϕ is the angle between the strike and the line of the section.

In the same issue of the *Bulletin*, Lyndon L. Foley presents a graph for performing the indicated operations. It is evident that for large angles of dip and small angles between profile and strike, Mr. Foley's graph reads inaccurately in projected angle of dip (termed here apparent dip).

Using the logarithmic form of Mr. Herold's solution, we may plot each of the three terms of the equation on three uniformly spaced parallel scales and obtain the nomogram of Figure 1, which is equally accurate for large and small angles of true dip and apparent dip. The fact that the angle between the strike and line of section can not be read accurately near 90° is unimportant, since a large change in this angle is required to produce a small change in the calculated value of the apparent dip.

It should be noticed that the nomogram is really two nomograms in one. When values of true dip are located on the heavy line, the values of the apparent dip are obtained on the heavy center line. When values of true dip are located on the light line, the values of the apparent dip are obtained on the light center line. This effective doubling of the nomogram back upon itself gives the accuracy in reading to be expected from a nomogram twice as long as is here used.

A nomogram of this sort is easier to use than a cartesian coördinate chart of the conventional type, in that a straight edge of any kind joining the value of the true dip and the value of the angle between the strike and the line of section will intersect the apparent dip scale at

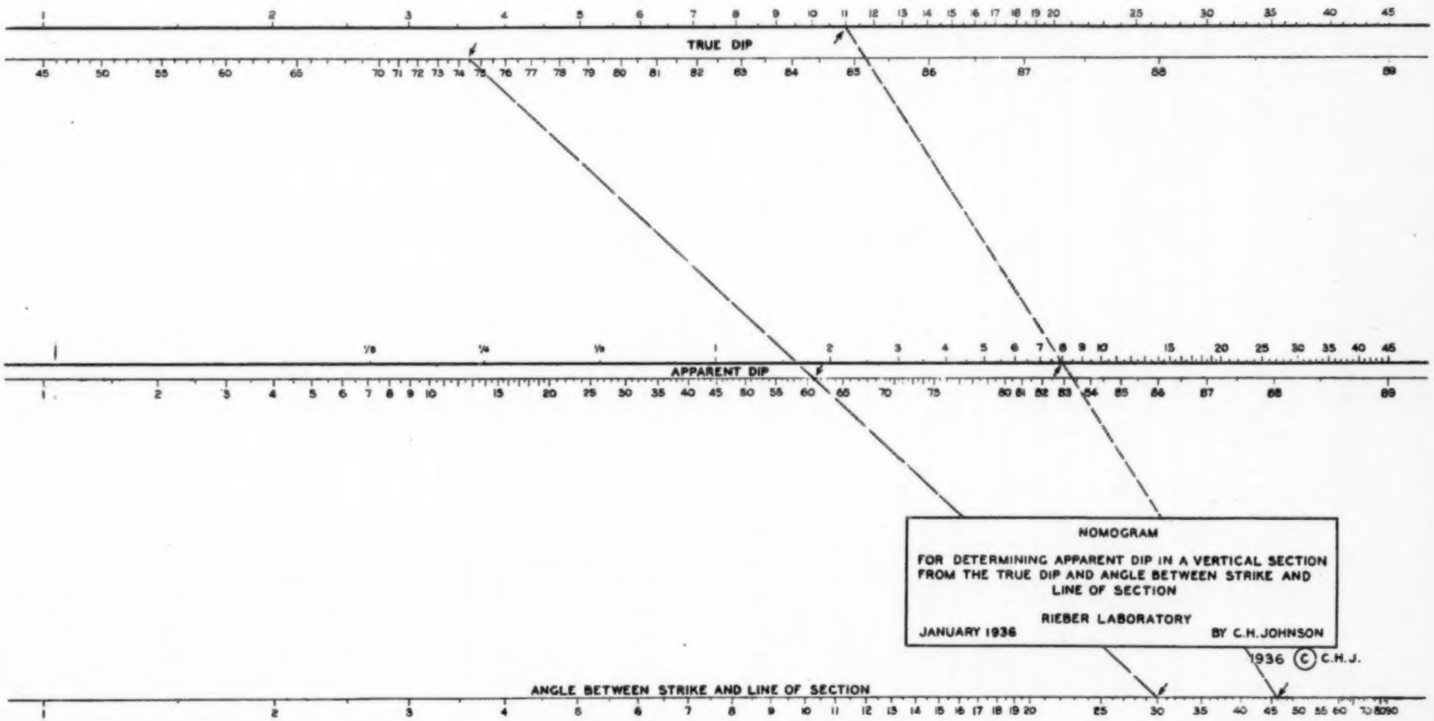

FIG. 1.—Nomogram for determining apparent dip in vertical section from true dip and angle between strike and line of section.

the desired value, while in the old type chart a line must be drawn perpendicular to each coördinate axis and the apparent dip found at the intersection of these two lines.

The dotted line illustrates a sample solution in which the value of the total dip is located on the *heavy* line at 11°, the angle between the strike and line of section is 46°, and the apparent dip in the vertical section is found on the *heavy* center line at 8°. The value calculated from the equation is 7° 58′−.

The dashed line illustrates a sample solution in which the value of the total dip is located on the *light* line at 74½°, the angle between strike and line of section is 30°, and the apparent dip in the vertical section is found on the *light* center line at 61°. The value calculated from the equation is 60° 59′+.

The nomogram described here has been used for several months by the staff and friends of Rieber Laboratory with a gratifying improvement in speed and accuracy as compared to the use of tables or older type graphs.

CURTIS H. JOHNSON[1]

March 19, 1936

[1] Chief of interpretation staff for Rieber Laboratory, consulting geophysicists, Los Angeles, California.

CORRECTION

GEOLOGY AND GEOPHYSICS SHOWING CAP ROCK AND SALT OVERHANG OF HIGH ISLAND DOME, GALVESTON COUNTY, TEXAS

In the article, "Geology and Geophysics Showing Cap Rock and Salt Overhang of High Island Dome, Galveston County, Texas," by Michel T. Halbouty, in the May *Bulletin*, page 569, line 15, the words "*Rotalia beccarii* (Linne)" should be "*Discorbis* cf. *D. vilardeboana*."

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 20, NO. 6 (JUNE, 1936), PP. 819-828

DISCUSSION

GONDWANA ROCKS AND GEOLOGY OF PETROLEUM OF SOUTHERN BRAZIL

The writer is very thankful to Chester W. Washburne for the constructive criticism of his book, "The Gondwana Rocks and Geology of Petroleum of Southern Brazil."[1]

The writer certainly does believe the country to be highly fractured and faulted and he desires to emphasize this in addition to the stratigraphic difference of key beds in adjacent wells, as shown in many of his cross sections, that could not be drawn, to be illustrative, on the same vertical and horizontal scales. As commonly used in petroleum well log studies for clearness of the stratigraphic succession, the vertical scale is proportionally increased, to which the attention of the reader is called. The reader is supposed to study the logs and sections carefully, in order to have a correct understanding of the matter.

The arguments that make the writer believe the region to be fractured and faulted are more than those stated by Washburne. Besides faults personally observed by the writer in several outcrops, mainly in the states of Paraná and Santa Catharina, and those quoted by Washburne himself near Piracicaba, state of São Paulo, the evidences stated in the book, on page 121, are the following.

1. Many contiguous wells, drilled in several areas distant from each other, show a considerable difference of level of the Iraty key bed, the strata remaining horizontal. This statement is not based on graphical deduction, as Washburne thinks, but on actual field observations, not only in the state of São Paulo studied by Washburne, but also largely in the states of Paraná, Santa Catharina and Rio Grande do Sul.

2. A large number of cores from the many wells drilled in all the southern states have been carefully analyzed by the writer and most of them showed evidence of intense fissuring and dislocations. Many of the fissures are lined with calcite. This fissuring could be produced only through a process of shattering of the strata.

On pages 45 and 122, as well as in other places of his report, the writer states that the fractures and faults are usually of a reduced vertical projection, and finally Washburne agrees that the faults he observed in São Paulo "must have insignificant displacement."

The writer thinks they are much more than insignificant, because an area as great as the Paraná Basin, most of it covered by the great masses of Paraná traps, and with a narrow sedimentary belt intensely cross-cut and traversed by intrusive bodies, ranging from batholiths many kilometers wide to innumerable dikes, sills, et cetera, must have been highly fractured in order to give passage to the basaltic masses that cut their way through the sedimentary system, particularly as in a great number of cases, they reached the surface.

[1] Victor Oppenheim, "Rochas Gondwanicas e Geologia do Petroleo do Brazil Meridional." Review by Chester W. Washburne, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 19, No. 11 (November, 1935), pp. 1701–06.

Then, apparently Washburne does not object to the region being fractured, but objects to it being faulted, because he did not see many surface faults in the state of São Paulo.

Washburne will probably agree with the writer that those fractures had either to precede the intrusions or to accompany them, as probably he will not think that all the intrusives of Southern Brazil penetrated the strata by some process of infiltration! Independent of the fact that the intrusives, after having penetrated into the system, produced dislocations and faulting through the uneven tension of the penetrated strata, the process of cooling of great igneous bodies within the strata, and the consequent contraction of these bodies, would be sufficient to produce intense fracturing and faulting.

As one of the other evidences of faulting, the writer cites the many water falls, cutting the courses of nearly all rivers of Southern Brazil, and here quite disagrees with Washburne who wants to see in those falls "anticlinal water falls" or attribute them to anticlinal structures that they do not represent.

The writer's idea of a faulted structure of the Paraná Basin is not entirely new, but is preceded by the opinion of K. Walther in 1927 on the similar structure of a part of the Paraná Basin in Uruguay.

Again, if faults do not form conspicuous outcrops and escarpments in this part of South America as they do in the approximately contemporaneous Triassic eruptives of South Africa, United States, and other places, it is mainly due to the exceptionally intensive erosion to which rocks are submitted in the tropical area of Southern Brazil with its deep peneplanation and lateritization that has continued since Triassic time.

With regard to the petroleum possibilities, the writer deals with this problem referring exclusively to the Gondwana rocks (Permian to Triassic), as the title clearly indicates. Therefore, he will not answer here Washburne's opinions regarding the underlying Devonian sediments, a study of which the writer will shortly present as a separate paper since these questions of interest to Washburne were not at the time discussed by the writer, who first concentrated on an analysis of the Gondwana rocks, as exhaustively as possible, before passing to the Devonian.

Unfortunately Washburne misinterpreted the writer's statements in the chapter on "Relations of the Structures to Oil Accumulations," pages 121–23, where it is several times repeated that the two principal structural characteristics of the basin—the structures due to the many intrusive bodies or the ones due to fractures and faults—are quite favorable for oil accumulations, being rather common cases in many oil fields. Again in his "General Conclusion," the writer repeats that the structural conditions are quite favorable for oil accumulations in Southern Brazil, but he considers the Gondwana sediments as not suited for oil generation, at which conclusion he arrives after a lengthy study of several years and a detailed stratigraphical analysis of all the known formations of the Gondwana system of Southern Brazil, Uruguay, and east Argentina, this being confirmed by all known Gondwana rocks on this continent, as well as in the Southern Hemisphere, in general.

Here, Oppenheim agrees with the statement of I. C. White (1906), "The probabilities are all against the discovery of petroleum in commercial quantities" in the Santa Catharina system of Southern Brazil.

The question of active seepages is, of course, in a general way very secondary, but is highly important for the peculiar structural conditions of the Paraná Basin where the great number of intrusive bodies and fractures of the strata connected with them offer exceptionally good conditions for an intercommunication of the lower strata with the surface, and, if great oil accumulations existed somewhere in this huge basin occupied by east Argentina, Paraguay, Uruguay, and Southern Brazil, there should be at least a single active indication of its presence. Moreover, the great number of borings, many of which reached the basement rocks, made during many years in the countries mentioned, showed no indications of oil accumulations.

Washburne is right in saying that the writer did not enter a detailed discussion or analysis of the "light oil" reported as found in the lower part of the Itararé. Failing to see it, or find corresponding laboratory reports, he considered that Washburne's statements on that subject were quite sufficient.

The writer agrees with Washburne regarding the rather westward and not northward movement of the ice sheets in Southern Brazil, as can be seen in the sketch, Figure 1, page 1726.

Finally, the writer is glad that, through the kindness of The American Association of Petroleum Geologists, a partly reduced version of his original paper appeared in English in the December, 1935, *Bulletin*, which will allow an even broader discussion of his ideas on the Gondwana rocks.

In the meantime, he takes the liberty to quote the opinion of as high an authority on Gondwana questions as Alexander L. du Toit, who, referring to the writer's original paper in a letter of November, 1935, says:

> I have read the work a couple of times and with extreme pleasure, considering it to be a highly important contribution to South American geology. . . . So far as your views are concerned, I am in very close agreement, not only as regards Brazil, but the rest of Gondwanaland. Much of your description of the Brazilian occurrences can be paralleled in South Africa, where the Dwyka shales, corresponding to the Iraty, form the source of the bituminous matter. Fortunately, here, the Government has long realized the futility of borings for oil in the Karroo basin.

The writer is again thankful to Mr. Washburne for his friendly criticism; he firmly believes that the presentation of new ideas and their discussion will bring us much closer to the truth, but time must be given the last word.

VICTOR OPPENHEIM

RIO DE JANEIRO, BRAZIL
March 4, 1936

CLIMATOLOGY OF BROWN'S HYPOTHESIS ON ORIGIN OF GULF BORDER SALT DEPOSITS

Levi S. Brown's recent article on the "Age of Gulf Border Salt Deposits"[1] is so dogmatically written that it will likely prove very misleading to persons unacquainted with details of geological history along the northern border of the Gulf of Mexico. While D. C. Barton and W. C. Spooner, in nearly nine pages of discussion immediately following the original paper, and a review by Barton[2] elsewhere, indicate a number of geological misconceptions advanced, limited space has prevented them from showing fully how "much funda-

[1] Levi S. Brown, "Age of Gulf Border Salt Deposits," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. XVIII, No. 10 (October, 1934), pp. 1227–96.

[2] *Jour. Geol.*, Vol. XLIII, No. 3 (April-May, 1935), p. 329.

mental argument . . . is based on strained or erroneous interpretation of data." The reviews have followed patterns of politeness and charity customary among American geologists. Had they appeared in the style of some of the publications abroad, such as *The Geological Magazine*, the true merits of the paper might have been thrown into sharper relief. It is my purpose to discuss the climatic aspects of Brown's speculation.

The Gulf of Mexico, during the period of salt deposition, is regarded as having somewhere between one-half and all its present area. Across its surface there is to be a wind velocity of 10 miles per hour. The water is to have a temperature of 80°F. The air is to have a temperature of 100°F. and a relative humidity of 25 per cent. Under such conditions the evaporation is to be 1.65 pounds per square foot per 24 hours. On the basis of one-half of the present area of the Gulf this means a total evaporation of 3.1×10^6 second feet. The Mississippi River is regarded as furnishing about one-seventh, the main rivers to the west about one-fiftieth, of the calculated evaporated waters. Run-off from other sources, subsurface inflow, and precipitation over the Gulf itself are not considered.

In support of a wind velocity averaging 10 miles per hour, Brown turns to the Southwest, where he believes the value is now exceeded. Phoenix, Arizona, records 5.7, and Yuma, 6.8;[3] Abilene, Texas, experiences exactly the postulated value and Amarillo averages 12.5 miles per hour. It is thus postulated that the average wind velocity over the brine-laden Gulf was similar to that of the Great Plains, or close to the maximum over flat surfaces in the United States. This velocity is used in Brown's calculations as the net rate at which water vapor was carried away from the Gulf and hence must be applied to the average for outflowing winds. Reversals in wind direction, which have no effect on the station averages previously cited, would, in the hypothetical case, require compensation in terms of velocity increase, so the Amarillo record would probably have been exceeded along the shores of the Gulf as pictured. Any precipitation resulting from convective up-draft would also need compensation in terms of increased wind velocity.

The water temperature of 80°F. "is the most reliable factor" postulated for the climatology of the salt forming period. This is based on the assumption that the anhydrite is original and forms only in brines with a temperature in excess of 77°F. The basic assumption that the anhydrite originally overlies the salt and is punched upward ahead of a rising salt plug is accepted by very few students of salt domes.[4] Most authorities agree that the anhydrite is secondary. It may well be due to temperatures in excess of 77°F. occurring at depth below the earth's surface that anhydrite rather than gypsum is associated with the salt and caps of many domes. At any rate, 80°F. is a very high temperature to postulate for a large water body in latitude 25° N. It is probably above the average along the thermal equator. The warmest oceanic waters on the globe reach a temperature only about 9°F. in excess of that value during the warmest month of the year.[5]

[3] All United States records cited in the text are from *Sectional Summaries, Climatological Data, U. S. Weather Bureau, 1930 edition.* All other records are from W. G. Kendrew, *The Climates of the Continents*, Oxford Press (1927).

[4] Summarized by H. V. Howe and C. K. Moresi, "Geology of Iberia Parish," *Louisiana Geol. Surv. Bull. 1* (1931), pp. 114–18.

[5] W. L. G. Joerg, reviewing Schott's regions, *Trans. Amer. Geophysical Union*, 16 (1935), p. 243.

The air temperature of 100°F. is regarded as "a conservative value," as higher temperatures are not uncommon in the southwestern deserts and "the Gulf of Mexico is appreciably farther south, and over the seas the diurnal fluctuations are less marked." The hottest station in Arizona is Yuma, with a mean annual temperature of 72.0°F., and mean maximum of 86.4°F. There is now a range in temperature between monthly normals over the Gulf of Mexico from 8°F. at Yucatan to over 20°F. along the east coast of Texas.[6] Under the "semi-arid" conditions repeatedly emphasized in Brown's paper, the range should be greater, so that in order to maintain the postulated average of 100°F. the warmest months should reach much higher values. El Golea, in the Sahara and famous for its high temperature records, has a mean annual temperature of 70.7°F., nearly 30°F. below that assumed for the Gulf of Mexico. Its warmest month, July, has a mean temperature of 93.4°F. In-salah, the hottest Sahara station listed by Kendrew, has values of 76.6°F. and 97.7°F., respectively. Kendrew states that temperatures average about 20°F. lower along the Atlantic seaboard of the desert. On the coast of the Red Sea, the hottest large water body on earth, Suakin averages 95°F. in August and 72°F. in January. The "conservative value" clearly exceeds any world record at present.

The average relative humidity of 25 per cent is supposed to represent that "over modern deserts." The 6 A.M. relative humidity of Yuma is 60 per cent, on a long record average, that at noon is 26 per cent and at 6 P.M., 26 per cent. In Phoenix the respective values are 57, 28, and 28 per cent. At Messilla Park, New Mexico, the average annual relative humidity is 46 per cent. The amount pictured for the Gulf is clearly well below that of any of these desert stations, but the comparison is not fair because all are inland. San Diego, California, has a desert climate but is situated on a sea coast and its average relative humidities are 80 per cent at 5 A.M., 65 per cent at noon, and 71 per cent at 5 P.M. We could hardly seek a better comparison than a desert station on the coast of the Red Sea. Suakin has an average relative humidity of 72 per cent in winter and 49 per cent in summer. Though it is absurd to postulate a climatic desert over the Gulf of Mexico anywhere near as arid as that over the Red Sea, we find that the relative humidities of the latter are so much greater than those postulated for the former as to render the assumed value ridiculous.

An evaporation rate of 1.65 pounds per square foot per 24 hours, using a reasonable density of water, is the equivalent of a mean annual evaporation rate of about 116 inches. At the Yuma Evaporation Station the value is 78 inches, with 90.6 inches during the year of maximum intensity. The Gulf of Mexico is thus pictured as having a rate about 50 per cent in excess of that of Yuma.

To summarize, Brown has postulated for the Gulf of Mexico a climate windier than the windiest, with air drier than the driest and hotter than the hottest, over water nearly as hot as any on earth to-day for a comparable area. Each value in itself approaches or exceeds an existing world record and nowhere are all approximated in combination. What effect would the air mass over such a Gulf exert on adjacent regions? Here we must yield to the infectious spirit of speculation.

[6] W. F. McDonald, "Seasonal Variation in North Atlantic Surface Temperatures," *Trans. Amer. Geophysical Union*, 16 (1935), p. 229.

If we postulate an inclination of the earth's axis similar to that of the present day, seasonal changes should be very similar in north temperature latitudes. A cap of polar air would be accentuated over continental interiors during the cooler part of the year, then as now. Over the Gulf region would exist an air mass with its 116-inch evaporation rate satisfied in order that brines be concentrated to deposit salt. Between these regions would exist a theater for the interaction of air masses far more sharply contrasted than any existing to-day. Thrusts of cold, dry, and heavy continental air coming in contact with hot air containing some 20 grains of water vapor per cubic foot would certainly create disturbances that would produce deluges such as are now unknown. The extent to which moisture in the modestly warm and moist Gulf air mass affects the rainfall of the United States to-day is readily apparent on maps of rainfall distribution. The tornadoes of the world are chiefly confined to the Mississippi Valley region for the reason that here is the one area in which cold polar air freely impinges on an air mass with tremendous potential energy in the form of heat associated with its high specific humidity. Air from the Gulf, under the conditions postulated by Brown, on arrival far enough northward and upward to have attained the moderate temperature of 50°F. would have lost up to about 16 grains of water vapor per cubic foot and would have released enough energy to create tornadic disturbances horrible to contemplate. Needless to say the rainfall would be so increased that existing river discharges would be meaningless in terms of inflow. The problem of disposing of waters evaporated from such a Gulf of Mexico as Brown pictures is not to be treated lightly, or ignored, as in the paper under discussion.

We have seen that an air mass is postulated more arid than any on earth today. Under what conditions might it originate? Deserts are identified with certain west coasts and with continental interiors for very well known reasons. There is no geological reason to believe that a continental land mass surrounded the Gulf of Mexico during middle or late Upper Cretaceous time, when Brown supposes the salt to have been formed. Sedimentary rocks suggest the absence, rather than presence, of great mountain ranges that might prevent ingress of surrounding maritime air. Paleontologic evidence reveals no extensive desert near-by where such an air mass might be thus heated and dried.

It is to be hoped that the plausible style of Brown's paper will not lead text-book writers unfamiliar with the problems connected with Gulf Coast salt domes to perpetuate, or entertain seriously, a thesis so violently in disagreement with geological facts and so impossible in terms of climatic implications.

Richard Joel Russell
Louisiana State University, School of Geology
Baton Rouge, Louisiana
March, 1936

It has long been the custom for geologists to regard the salt deposits as evidences of "aridity," "desert conditions," et cetera, the assumption arising through the necessity for an excess in rate of evaporation over that of inflow. For many years it has been my contention that the climatic significance of salt deposits has thus been dismissed too lightly, and that the actual climatic

conditions at the time of salt formation may have been appreciably less rigorous than these terms imply. Rohwer's formula has been developed and found to hold for the calculation of rates of evaporation over artificial tanks in industrial operations, where the several variables involved are accurately known. No formula is known that can be applied to the problem where enormously large, natural basins are involved—that is, several hundred miles in diameter with commensurate depths. My attempt to apply Rohwer's formula for calculation of a possible rate of evaporation over the Gulf of Mexico was intended only to convey some idea of the tremendous amounts of water lost through evaporation under certain assumed conditions.

Mr. Russell's discussion appears to me anomalous in that it is both pointed and pointless. It is pointed in that he has supplied welcome, accurate data respecting the variables that I had assumed, data many of which were not available to me at the time my paper was written. It is pointless in that substitution of values that he prefers does not change the fundamental nature of the conclusions drawn. Rather they tend to confirm my conclusions in that he has shown the so-called "desert conditions" to be less rigorous than I had postulated, and, whatever the conditions assumed for illustrative calculation, the factual existence of the salt to-day can not be denied.

Mr. Russell evidences a rather careless reading of my paper in several instances. This he can remedy by more careful study, and it is inappropriate that the space of public print should be used to call such particulars to his attention. It is a matter of general interest, however, to answer two sentences in his discussion, wherein he departs from his expressed intention of discussing the climatic aspects of my paper. To these I take unqualified exception.

> The basic assumption that the anhydrite originally overlies the salt and is punched upward ahead of a rising salt plug is accepted by very few students of salt domes. Most authorities agree that the anhydrite is secondary.

Mr. Russell evidently intends the word "secondary" here to signifiy adherence to the theory of cap-rock accumulation as a residual material from solution of the salt in ascent. My contacts of many years lead me to believe that most authorities are inclined to the sedimentary theory, and, of those who adhere to the residual theory, I am acquainted with a number who hold to that theory only because of a lack of explanation as to how calcium sulphate followed by calcium carbonate can occur through sedimentary deposition following immediately *above* salt. That was the problem that I attacked in my former paper. It has been somewhat of a disappointment to me that the true merits of the paper have not been thrown into sharper relief, as Mr. Russell avers might have been the case if it had appeared in *The Geological Magazine*. I strenuously object to the implication that our British brethren are lacking in either charity or politeness, though, so far as criticism of my paper is concerned, I am unconcerned about either.

Adherence to the sedimentary theory of cap-rock origin on my part is based entirely on a broad personal study of cap-rock materials, petrographic and otherwise. Supporting evidence adduced was printed in the *Bulletin* for May, 1931. My conclusions were drawn quite apart from any knowledge as to how such a sedimentary sequence might be deposited, and were independent of the opinions of others, either majority or minority, pro or con.

I heartily endorse Mr. Russell's determination to guard against the dissemination of mis-information. We can not be too zealous or too relentless in

charting the shoals upon which the tender minds of the uninitiated might founder. On the other hand the sum of human knowledge is advanced far more potently by contributions of independent thought. Mr. Russell may choose to accept the opinions of those that to him constitute a majority, but I feel that he will enjoy the independent solution of a simple problem in sedimentation as a further criterion upon which to base his convictions. The outlines of the problem are those familar to and generally accepted by geologists through the past many years.

As an introduction, it may be said that physico-chemical laws are immutable. Application of these laws has been made in detailed, small-scale laboratory studies of the behavior of saline solutions on evaporation, and has produced an abundance of accurate information. Their detailed application to evaporational studies, where enormously large and correspondingly deep, natural basins are under consideration, has been only superficial. Let these laws be kept clearly in mind in reasoning out the formation of salts with evaporation in such large basins.

In such a basin it is essential that the basin be completely isolated so far as outflow is concerned. It has long been recognized, however, that the amount of salt present in these large basins—for example, the German Permian deposits—is considerably in excess of the amount that could result from complete evaporation of the sea water originally in the basin, calculated on the basis of the present salinity of the sea, and there is no evidence that the average salinity of the sea in the past has been greater than that of the present. Consequently, it is essential to consider a more or less continuous inflow during evaporation, and, so far as dissolved salts are concerned, this inflow can enter only along the margins of the basin. This has been the origin of the bar theory proposed by Ochsenius, though adequate consideration of marine shore erosive processes should convince anyone of the unlikelihood that any such shallow bar could exist through the 200,000 or more years of the evaporational process. Also there is unlikelihood that such large basins should be entirely devoid of terrestrial drainage, even under the most arid conditions, and Mr. Russell has submitted figures showing that "desert climates" are not as rigorous as might be supposed. Moreover, the problem is the same whether the increments be supposed to enter from the sea over a shallow bar or through land drainage.

The problem, thus, is one of a large basin undergoing evaporation as further contributions continue; the only requisite is that the total lost through evaporation must be somewhat greater than the total amount of water entering during the same period. Let a series of cross sections of such a basin be drawn showing the location, amounts, and mutual relations of all of the major salts formed in all stages of the evaporative process. Under these conditions, it will be found that the operation of physico-chemical laws will result in the development of calcium sulphate, followed by calcium carbonate, immediately above the salt, just as it is observed in the cap rock over salt domes. I shall be glad to have Mr. Russell make full use of my experience with this problem, and will look forward to the appearance of his cross sections within a year or so.

LEVI S. BROWN

HUDSON, NEW YORK
April 17, 1936

PHOTOGRAPHY FOR GEOLOGISTS

In a recent paper on photography, F. T. Thwaites[1] has attempted to cover an extremely broad subject in rather limited space. Although this attempt probably has its justification in the encouragement of better geologic photographs, the presentation is rather too detailed and too complicated for those with very limited experience in photography, and yet, it contains little, if anything, which is new to the more thorough students of photographic methods.

It is surprising that no mention is made of a collection of tables as valuable as those to be found in the "*Wellcome*" *Photographic Calculator, Handbook and Diary*.[2] Although there are other good tables which contain such information as: filter factors, relative exposures for different types and makes of emulsions, depth of focus tables, et cetera, some such handbook is indispensable to those with limited experience. In connection with laboratory methods, another publication which is very useful is *Photomicrography*.[3]

Thwaites (page 195) gives an illustration of a filter mounted in a metal cell. This is not a very convenient way of using filters if the number of filters to be used interchangably is greater than three. Filters mounted in this manner are so expensive as to make it worth while to obtain a combination filter holder and lens hood. Quite inexpensive, yet serviceable, filters may be made by cementing Wratten gelatin filters between selected[4] micro-slides (2 by 3 inches) with Canada balsam. Great care must be used if the drying of the balsam is to be hastened by heating, since heat in an amount above that comfortable to the hand will cause the gelatin to buckle. Such filters will fit the old-style filter holders adaptable to square and rectangular filters.

No mention is made of Wratten filters X_1 and X_2, although these are the filters recommended for correct rendering in monochrome with the newer panchromatic emulsions. Surely a green filter of some sort is useful in certain types of work. Blackwelder[5] has pointed out the value of the violet filter for increasing the contrast of light-colored outcrops, sand dunes, et cetera. Of the Wratten series, K_1, K_2, and K_3 (K_3 is now considered obsolete), K_2 is probably the most useful. If some penetration of haze is desired, a G filter should be employed. It is a question whether or not there is any real advantage to be gained by the use of filters denser than G for ordinary purposes, since these require long exposures (when used with a small aperture) and perturb the tonal values in the monochromatic rendering of colors—for example, fields of yellow grain become snow-white, the sky blackens, water becomes dark.

It was correctly stated that lenses of shorter focal lengths have greater depth of focus, but these lenses have a very objectionable feature. They produce appreciable distortion of perspective, especially when used for near objects which have considerable depth.

[1] F. T. Thwaites, "Field Photography for Geologists," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 20 (1936), pp. 186–214.

[2] Published annually by Burroughs Wellcome and Company, New York City. Price, 75 cents.

[3] Published by Eastman Kodak Company, Rochester, New York. Price, 50 cents.

[4] Selected for their plane surfaces and uniform thickness. Only a small per cent of the better grade slides are suitable for this purpose. They may be tested by examining their interference rings when in contact with an optical plane or by the manner in which they reflect a regular pattern. The first method is more critical.

[5] Eliot Blackwelder, "Hint for Better Geological Photographs," *Science*, Vol. 73 (1931), p. 214.

Although undoubtedly aware of the fact, Thwaites did not point out one precaution necessary in the use of extremely rapid emulsions. The inexperienced person is likely to over-expose these emulsions, due to lack of familiarity with their extreme speed, with the result that the pictures are totally lacking in contrast or brilliancy.

It is always best to make new exposures, where possible, in case of failures due to improper exposure or development but, nevertheless, it is frequently practicable to correct these mistakes (except both under-exposure and under-development) by means of intensification or reduction. Intensification increases contrast, whereas reduction either increases or decreases it (or neither) depending upon the particular process employed. These processes are no more difficult than ordinary development and require only a few additional chemicals.

Although Thwaites' paper is one of the best papers on photography to have appeared in the geological journals, it is indeed difficult, if not impossible to summarize the photographic problems of geologists in a paper of even moderate length. At best a short paper can not hope to cover the vast sources of information which are contained in a number of inexpensive publications on photography, and most of these have already come to light.

Most geologists have access to adequate photographic equipment and the results can only be improved through determination on the part of the geologist.

DUNCAN McCONNELL

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MINNEAPOLIS, MINNESOTA
March 25, 1936

In reply to the discussion by Duncan McConnell of "Field Photography for Geologists" it seems necessary to state that the paper was first prepared in 1927 for use with a class in field mapping at the University of Wisconsin. This course was intended to cover the use of instruments (except geophysical instruments) which are commonly used by geologists. The paper has been revised several times. Experience has made the writer feel that his presentation of the complex subject of photography does actually help persons, who have been trained in other branches of sicence, to understand the basic reasons which cause certain practices to be advised. Every effort was made to avoid so far as possible all mention of trade names of apparatus in order to prevent any charge of advertising the products of a particular firm. This fact explains most of the omissions mentioned in the discussion.

The use of filters mounted in metal cells was advised after field experience with both types of mountings. Fittings which are well adapted for the studio or to large cameras on special photographic expeditions are too cumbersome for use with limited equipment and with small cameras. Mr. McConnell's suggestion of the use of square filters in a special lens hood is a good one. The writer has designed other forms of mounting filters but abandoned them because they require too much special construction. The experience of the writer indicates that red filters are absolutely necessary under bad haze conditions.

Other points raised by Mr. McConnell in his discussion are either matters which were specifically excluded from the paper, for instance problems of development, or were mentioned in general language only for reasons previously stated.

F. T. THWAITES

MADISON, WISCONSIN
March 31, 1936

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 20, NO. 6 (JUNE, 1936), PP. 829-838

REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library and available to members and associates.

Petroleum. Twenty-Five Years Retrospect. By twenty-five authors. The Institution of Petroleum Technologists, London (1935). 219 pp., 42 illus. Price, $2.00.

This volume was sponsored by the Institution of Petroleum Technologists as its contribution to the Silver Jubilee of H. M. King George V. It also commemorates the twenty-first anniversary of the founding of the Institution itself. The general theme of the book is briefly to record the progress of all phases of the petroleum industry from 1910 to 1935.

Since twenty-five papers are included in two hundred pages it is evident that each paper can be little more than a summary of its subject. Refining, its processes and products, together with various forms of transportation, take up more than half of the volume. Petroleum geology, prospecting methods, geophysics, and petroleum engineering are all discussed in the first seventy pages. Eight pages are allocated to natural gas. The two final papers discuss the present status of the Scottish oil shale industry and production of oil from coal.

Naturally this publication contains many observations of interest to technical men in the oil business. However, it seems that its chief value will be to those unfamiliar with the oil industry who are seeking a quick survey of it.

W. B. WILSON

TULSA, OKLAHOMA
April, 1936

"Die Gebirgsumrahmung des Nordamerikanischen Kontinents" (The Mountain Framework of the North American Continent). By RUDOLPH SCHOTTENLOHER. Special reprint from *Mitteilungen der Geographischen Gesellschaft* (Vienna), Vol. 77, Nos. 7–9 (1934), 17 pp., 1 map.

The author's conception of the unity of North America, as expressed in the following paragraph, is interesting whether we care to accept his views or not.

Eurasia and North America present opposite types of continental evolution. The centrifugal nature of Eurasia contrasts with the centripetal nature of North America. Edward Suess has in these words sought to make clear to us the unity of Asiatic mountains: "As a drop of water in the ocean is our comprehension of the limitless miraculous power, circle-born, that emanates from the Eurasian backbone." There has not been hitherto a corresponding picture of North American unity. We have seen in the eastern and western mountains of North America sharp contrasts in age and form. We have considered calling the Appalachians the western, and the Rockies the eastern wings of an Eurasian mountain system, the two continent-embracing wings of different tectonic worlds holding a rendezvous here opposite the Eurasian point of origin. We have noted the geologic leanings of eastern North America on Europe and have reconstructed an adherence to Europe that would seem at present to be broken by a drifting away, the Cordilleras being a sort of tidal swell on the forefront of a westward-driven continental clod.

If the authors of such tectonic pictures had lived in the middle of North America as did Schottenloher while a visiting student at Drury College in 1931–32, they would have had to consider in opposition to their views, so he says, an obvious unity of mountains, an interior with a surrounding frame.

I. The three main phases of folding, the Permian-Appalachian of the east, the Jurassic-Nevadan of the Pacific basin and the Late Cretaceous-Laramie of the Rockies, as well as earlier and later folding, are all of one order; they run parallel with the edge of the continent. The southern Appalachians curl around westward and through their extensions and parallel ridges consummate a curving connection with the ancestral Rockies, the connection with the Cordilleras not quite complete in northeastern New Mexico. A large bow thus stretches like a horseshoe from Newfoundland to Alaska.

II. In Eurasia geosynclinal mountains border the continent, the mountain growth being from within outward. In North America girdling geosynclinal mountains, as set forth by Charles Schuchert, lie within the ancestral hard rock mountains, the evolution of new mountain generations continuing inward. The direction lines of North American mountains are indicated by the particular inner-continental positions of their mother geosynclines. Radial sequence of ocean, borderland, geosyncline, and continental nucleus, is the rule in North America. The marginal area between continent and ocean is the mobile tectonic zone, a fact already recognized by North American geologists who, also, have recognized the importance of these tectonic line directions on the history and permanence of their continent.

III. The original positions of geosynclines was the same east and west. The mountains that developed therefrom differed in sort, origin, and age. The mechanics back of the alpine type thrusting were alike east and west. Greater Laurentia was the foreland against which the marginal orogenic movements were directed.

IV. The domes of the interior are at intersections of the various anticlinal folds that are aligned parallel with, and in front of, the several rim mountain segments whose shoves made them away from the geosynclines on the continental nucleus.

V. The posthumous epirogenic movements which made the morphologic mountains of to-day reproduce the uniform arrangement of North American orogeny.

VI. All geographical knowledge of North America concerns an interior plain encircled by mountains. The one center of gravity is the interior plain. Eurasia is centrifugally dispersed, North America centripetally united.

VII. In conclusion, North America was not put together out of several independent foreign elements but was formed in one mold. The mountain building has evolved since the beginning of Cambrian time not from in out, but from out in.

IRA OTHO BROWN

SAN ANTONIO, TEXAS
March, 1936

Lehrbuch der Kohlenpetrographie (Textbook of Coal Petrography). By ERICH STACH. Gebrüder Borntraeger, Berlin (1935). 292 pp. Price: paper, RM 18; cloth, RM 20.

Lehrbuch der Kohlenpetrographie, written as a textbook on coal petrography, endeavors also to indicate the possibilities of the application of science to the practices in the coal industry.

The work is based primarily on researches carried on at the Prussian Geological Survey. The microstructure of coals has been examined on a large number of polished surfaces. No thin sections of coal have been made by the author.

The first chapter on the dolomites and siderites containing organic plant remains is a good and most natural introduction to the study of the structure of the plant components as found in the various types and ranks of coal. The original descriptions of Marie Stopes' ingredients of bituminous coal as vitrain, clarain, durain and fusain, have not been accepted as such by the German investigators. Clarain was rejected as an ingredient and the three remaining were adopted with a change in the ending to "it" instead of "ain." The change is regarded by Stach as very essential, as the ending proposed by Stopes is not in accordance with the international rules, and the terms "vitrit," "durit," and "fusit" correspond to the minerals in the inorganic rocks. For the past ten years there has been considerable confusion in nomenclature in the literature on the microstructure of coals. The correlation of the various terms as they are used by different schools of investigators, with concise definitions and succinct explanations given in the book will be of great assistance to all those beginning the study of coal petrography.

The structure of all three components is described in considerable detail. The appearance and physical characteristics of each component, such as index of refraction, specific gravity, fracture, joints, fusion or plastic zones, are compared.

The subject of the coalified wood, vitrain, anthroxylon, xylit, et cetera, is carefully covered and well illustrated by figures with descriptions.

The explanation of the conditions leading to the preservation or obliteration of the woody cell structure is very clear and extremely helpful to an understanding of the various types of wood and parts of woody tissues entering into the formation of coal. Accordingly, vitrain is divided into wood vitrain, periderm vitrain, et cetera. The anatomical features of the woody coals of various geologic ages are discussed in considerable detail and well illustrated.

Vitrains are divided into three kinds or classes: (1) vitrains with recognizable cell structure, termed as structural vitrain or pro-vitrain; (2) structureless vitrains, or eu-vitrains; and (3) detrital vitrain, made up of vitrain particles. The first class or sub-division is composed mostly of periderm, parenchyma, xylem and cuticular tissues. The third class constitutes the "groundmass" of the old authors and corresponds to the translucent attritus of Thiessen.

The humic groundmass, through gradual transition, is changed to opaque groundmass. Spores and pollen grains are regarded as the "bituminous bodies" of the coal. A number of illustrations of spores and pollen grains are given with the discussion of Patonie's symbols for spores.

Coals made of cuticular tissue are described, and particular references are made to Moscow coal (Mississippian age), to the coal of Creek Flat, and to a cuticular coal from northern France, and also to Upper Silesian coal of this type.

Durains are subdivided by the author into three classes, according to their structure: (1) particles, (2) chips, and (3) opaque grains. The last class is synonymous with Thiessen's opaque attritus. Bogheads and cannel coals are classed as "pure" durains. Durains composed of woody plant matter are highly vitrainous durains or "homodurain" or "clarain" (the term rejected in an earlier chapter of the book).

"Durain," as used by Stach, is covered entirely by Thiessen's term "attritus" and does not quite correspond to the original definition of Stopes. Some of the interpretations of durains, judging from the illustrations, may be questioned.

It must be pointed out that in spite of the unqualified praise given to the polished surface method of the study of the microstructure, the author is forced to rely on thin sections in describing certain types of coals and illustrating their anatomic features.

Fusains in turn are divided into "hard" fusain and "bed" fusain, or mineralized fusain. Their characteristics and the various theories of formation are adequately discussed.

In addition to the examination of coals and their components, the microstructure of oil shales is presented. Oil shales are defined as the carbonaceous sediments with an ash content ranging from 30 to 50 per cent.

The concluding chapters are devoted to qualitative and quantitative petrographic coal analyses, descriptions of apparatus, and illustrations of the methods of the study of coal grains and coal dust by the comparison microscope.

Undoubtedly analyses of this type are of great assistance in the study of problems in coal technology, such as the washing of coals and the use of various blending mixtures in the production of high quality coke.

The book is illustrated with tables, diagrams and a large number of excellent photomicrographs of polished surfaces of coal and oil shales (taken with oil immersion lenses at $\times 200$ and $\times 1{,}000$). The list of literature, consisting of 919 titles frequently and judiciously cited, is a very valuable asset to this excellent contribution to the literature on the microstructure of coal and other carbonaceous sediments.

TAISIA STADNICHENKO
Associate geologist

UNITED STATES GEOLOGICAL SURVEY
WASHINGTON, D.C.
April, 1936

"Early History of Texas Red-Beds Vertebrates." By A. S. ROMER. *Bull. Geol. Soc. America,* Vol. 46 (1935), pp. 1597–1658.

This paper is of interest to all geologists who are studying the stratigraphy of Permian rocks. It presents new evidence regarding the late Paleozoic vertebrate succession, and discusses its bearing on the problem of the Pennsylvanian-Permian boundary. This evidence is little understood, except by vertebrate specialists, so that most recent discussions by others of the Pennsylvanian-Permian problem have failed to consider it adequately, and have utilized only the physical, invertebrate, and plant evidence. One cause of this failure to consider vertebrate evidence is that the stratigraphic relations of the vertebrate fossil-bearing beds have been poorly known. One of Romer's contributions has been to place the fossil-bearing beds in known formations of the Pennsylvanian and Permian succession, and thus to correlate events in vertebrate history with better known events worked out by other lines of evidence.

One of the most important regions for late Paleozoic vertebrates lies in Archer and Baylor counties in north-central Texas. The strata here are red

beds, and the fossils bear the imprint of this environment. Until recently, the relation of the fossiliferous beds to the marine Pennsylvanian and Permian beds farther south was imperfectly known, but many horizons have now been traced northward through the area. Romer has determined the relation of the fossil localities to the traceable horizons, and has thus been able to assign them to their appropriate formations. Not only was he able to locate long-known occurrences, but during his field work he discovered still other vertebrate-bearing zones, mostly lower in the section. The collections thus range in age from the Pueblo formation of the Cisco group to the Arroyo formation of the Clear Fork group. The assemblage of fossils now obtained permits many generalizations regarding the development of the various genera.

The Pueblo formation, in which the oldest vertebrates are found, marks the initial deposition of red beds of continental origin in the region. The underlying formations (Harpersville and older) have so far yielded no vertebrates, but since they are largely marine they would not seem to afford a promising field for collecting. The Pueblo vertebrate fauna, according to Romer, has many resemblances to the better known later vertebrate faunas. He says,

> All the fish types of the Wichita beds are present [in the Pueblo] and no new types are found. Of the seven common Wichita tetrapod genera . . . all are present in the earlier beds. . . . In addition, some of the rarer upper Wichita types are present (page 1626).

The chief difference is in size, those in the younger beds being larger than those in the older.

The greatest change in the vertebrates, he finds, occurs a considerable distance above the Pueblo, between the Belle Plains and Clyde formations. A number of vertebrate genera occur in both the Clyde and the older formations, but many genera common in the older formations do not continue into the Clyde. Romer suggests that these became extinct before Clyde time.

> Equally striking are the new animals at this time among the cotylosaurs—*Captorhinus*, *Labidosaurus*, and *Pantylus* are advanced members of this group quite unknown in the Wichita fauna, but comparatively common here (and the first two in higher formations as well) (page 1613).

The still more abundantly fossiliferous Arroyo formation above has a fauna like the Clyde, but unlike that of beds below the Clyde. Some new forms appear in the Arroyo.

At a level near the top of the Arroyo formation "fossils cease, and, except for some finds of footprints in other areas, the known history of Paleozoic vertebrates in America is closed" (page 1615).

The Texas red beds fauna has generally been assumed to be of a type transitional from the Pennsylvanian into the Permian, and to be distinguished from the typical coal swamp Pennsylvanian faunas by the presence of reptiles and the poorer development of amphibians. Study of the Texas fossils themselves suggests to Romer, however, that "the fauna must have its roots deep in the Pennsylvanian" (page 1639), and the earlier existence of its forebears can be seen in small collections from older beds of other regions. Moreover, he concludes that the seeming contrast between the coal swamp faunas and red beds faunas is more apparent than real. The amphibians of the two facies are closely related, and differ chiefly in abundance. Their abundance in the coal swamp faunas seems to be because this environment was more favorable to them than the dry environment of red beds deposition. On the other hand,

the dry environment was more favorable to reptiles than the swamp environ ment.

Romer thus pictures the development of the vertebrates as proceeding uninterruptedly from early in Pennsylvanian time to the end of Belle Plains time, but with a gradual change from coal swamp to red bed conditions, which tended to favor the reptiles rather than the amphibians. Similar changes in the make-up of the floras as a result of the same environmental change have been recognized by White.[1] Romer considers that a much more significant change in the vertebrate faunas took place between Belle Plains and Clyde time, which extinguished old forms and accelerated the evolution of new ones.

With this evidence in hand, the author then discusses the Pennsylvanian-Permian boundary, which has been placed at quite different levels by various stratigraphers and paleontologists. His thorough review, not only of the world-wide vertebrate evidence, but also of the physical, invertebrate, and plant evidence, may be recommended to all who are interested in the problem. He aptly states that revisions of the boundary have been variously based on:

> (1) attempts to make closer correlations with the type sections of the systems concerned; (2) carefully considered projects of systematic revision, based on consideration of world-wide utility; or (3) arbitrary changes made merely to fit local conditions. Unfortunately in this instance the last motive seems to have predominated (page 1643).

The reviewer believes that the problem has been further complicated by the opinion on the part of certain stratigraphers that geologic systems or series such as the Permian, are natural units, set off from one another everywhere by orogeny and important life changes. To find such orogenic and faunal boundaries, the geologist presumably needs only to study the exposures thoroughly enough. The geologic divisions now accepted do not, however, seem to be such ideally natural units. Instead, they are largely artificial, for their study involves not only a consideration of natural features, but also consideration of the original definition of the division at the type locality, and the use which has been made of it since. To the reviewer it would therefore seem that the problem would be approached more realistically if stratigraphers should assume that systems and series were arbitrary units, created in order to express better the successive life changes and physical changes on the earth. On the borders between such divisions one would naturally expect a transition from the features of one to those of the next. As Romer says:

> The breaking down of many supposed sharp lines of cleavage into gradual transitions is a comforting sign of increasing knowledge. This search for more "natural" lines of division seems to lead nowhere. For it is probable that such lines will, with still further research, prove to be contemporaneous with gradual lithologic and faunal changes in other regions (page 1656).

The vertebrate evidence from north-central Texas suggests to Romer that the boundary between the Pennsylvanian and Permian series should lie between the Belle Plains and Clyde formations. Following Cummins' original definition, he considers this to mark the top of the Wichita group, although common usage to-day places the top of the Wichita above the Clyde. In Russia according to Romer, this would correspond approximately to the top of the Uralian, so that his proposed base of the Permian is apparently the same as that which has long been accepted there. In the United States he correlates

[1] David White, "Some Features of the Early Permian Flora of America," *Report of 16th International Geological Congress*, preprint (1934), p. 2.

the north-central Texas horizon with the top of the Wolfcamp and Hueco formations in trans-Pecos Texas, and with a level above the Abo sandstone of New Mexico and the marine "Permian" beds in Kansas.

With these correlations the reviewer is in general agreement, although he feels that on some of them the evidence is not sufficient to warrant the positive conclusions given in the paper. Thus, one of the reasons given for assigning the Wichita to a Uralian age is Beede's suggestion that *Schwagerina* is to be expected "to extend . . . upward to about the Bead Mountain-Beaverburk, at the tip of the Wichita as here defined" (page 1645). This is unjustified, because at the time Beede wrote, the fossil had not been found in the region and its occurrence there was a matter for speculation. Since then, it has been reported from the Moran formation, much lower down, and no existing evidence suggests that it ranges much higher. Also, one of the reasons given for correlating the Wolfcamp with the Uralian is the probable Uralian age of the *Uddenites* fauna, considered on page 1644 to occur in the Wolfcamp formation. This fauna is now assigned to the Gaptank formation, below the Wolfcamp, and correlations implied by it have no direct bearing on the age of the Wolfcamp itself. The Wolfcamp contains few ammonoids, and these have not been studied. It is therefore incorrect to say, as on page 1655, that the genus *Metalegoceras* "ranges through the Wolfcamp." On page 1629, where the *Uddenites* zone is classed with the Gaptank, it is correlated with the Brad, Caddo Creek, Graham, Thrifty, and Harpersville formations in the Pennsylvanian of north-central Texas. The observations of F. B. Plummer suggest, however, a resemblance of the *Uddenites* fauna only to the ammonoids of the Wayland shale member of the Graham formation. Moreover, the *Uddenites* zone of the Gaptank has a thickness comparable to that of the Wayland member, so that it would seem safer to correlate it with that bed alone. Romer's correlation of the base of the Leonard formation of west Texas with the Clyde formation of central Texas seems to rest entirely on the reported resemblance of ammonoids at those horizons in the two regions (page 1630). Final decision on this must await further work, such as that now being done by F. B. Plummer. A part of the Leonard fauna has a much closer resemblance to ammonoids higher in the central Texas section, in the Clear Fork and Double Mountain formations.

In considering the top of the Wichita as the base of the Permian, Romer is at variance with many stratigraphers and paleontologists in the United States, who in recent years have been drawing the Pennsylvanian-Permian boundary lower in the section. These geologists consider that the base of the Permian is below the zone of *Schwagerina*.[2] This fossil, whatever its range elsewhere, seems to characterize a widespread and restricted zone in the south-central United States, which occurs near the base of the Wichita group, and of the Wolfcamp, the Hueco, and the "Permian" of Kansas. The reviewer has himself favored such a decision—partly because of the unconformity which occurs beneath it in the Southwest, and partly because it provides a convenient, traceable zone in field work.[3]

[2] See, for example, Charles Schuchert, "Review of the Late Paleozoic Formations and Faunas, with Special Reference to the Ice-Age of Middle Permian Time," *Bull. Geol. Soc. America*, Vol. 39 (1928), pp. 776–77.

[3] P. B. King, "Permian Stratigraphy of Trans-Pecos Texas," *Bull. Geol. Soc. America*, Vol. 45 (1934), pp. 719–20.

Romer's conclusion is based upon a somewhat different philosophy than that of those who would place the Pennsylvanian-Permian boundary at the base of the *Schwagerina* zone. He is more inclined than they to adhere to older definitions, and thus to use the generally accepted boundary in Russia as the standard. Moreover,

> it will be noted that the correlations here attempted are based on extinctions. Correlation on this basis is frowned upon by most invertebrate workers, and the first appearance of new forms is thought to be much more satisfactory. The writer fails to see the force of such arguments as have been advanced in support of this view. True, the time of extinction of a form or group may vary from region to region; but this is equally true of the time of appearance (page 1652).

The gap between the boundary advocated by Romer and that by the other stratigraphers seems, in fact, to mark the interval between the first appearance of Permian-like forms and the final extinction of Pennsylvanian-like forms. Thus, in trans-Pecos Texas, R. E. King has found that many Pennsylvanian brachiopods persist through the Wolfcamp and Hueco formations, but that they are associated (particularly in the Wolfcamp) with new fossils which foreshadow the development of the true Permian, or Guadalupian, fauna later on. In the overlying Leonard and Bone Spring formations the Guadalupian fauna appears in full development, and brachiopods of Pennsylvanian type are absent. G. H. Girty has also noted the striking change in fauna on proceeding from the Hueco to the Guadalupian beds. Using the first appearance of new forms, the base of the Permian might be considered to lie at the bottom of the Wolfcamp and Hueco formations, but using the extinction of old ones it would seem to lie at their top.

To the reviewer, some inconsistencies seem to exist in Romer's argument. In north-central Texas his proposed boundary depends on the sharp contrast between two adjacent vertebrate fossil horizons, and this contrast depends on the material that has been collected. Is this not merely another "natural" boundary, and might not its prominence tend to disappear with further collecting here and in other regions? The accepted base of the Permian in Russia, at the top of the Uralian, lies considerably lower than the base of the Permian as originally defined by Murchison. Was it not agreed upon by the Russian geologists as representing a more "natural" boundary than that first proposed?

The reviewer must confess that he lacks any clear convictions as to where to draw the Pennsylvanian-Permian boundary, and that he finds the necessity of deciding what beds are Pennsylvanian and what are Permian to be more irritating than interesting. The important thing to the stratigrapher is to know the correlation of events across the continent and around the world, without regard to what system or series they may be assigned. In this respect the reviewer wishes to see more work along the lines suggested by Wheeler,[4] but he would be inclined to oppose at present such wide application of the stages in Russia as that undertaken by Wheeler. The Russian stages seem at present to be undergoing extensive revision and correction by the geologists working there, and until their results are better known, correlations based on the Russian stages are unsafe. We need a more thorough knowledge of the

[4] H. E. Wheeler, "The Carboniferous-Permian Dilemma," *Jour. Geol.*, Vol. 42 (1934), pp. 68–70.

fossil zones in the late Paleozoic from which to build a better conceived system of time stages. Such knowledge is increasing from year to year as the various groups of fossils are studied, and Romer's contribution to the vertebrate succession is a vital aid to such work.

PHILIP B. KING

UNITED STATES GEOLOGICAL SURVEY
WASHINGTON, D.C.
March 23, 1936

"Fortschritte der Ölgeologie" (Progress of Oil Geology). By KARL KREJCI-GRAF. *Geologische Rundschau* (Berlin), Bd. XXVI (1935), Heft 1–2. 65 pp.

Krejci-Graf has reviewed 500 papers on oil geology, and summarized the thought in this short paper. He lists 300 titles and refers to most of the latter in his discussions of: origin, alteration, and migration of the petroleums, manner of occurrence of petroleum in its deposits; chemistry and physics of petroleum deposits; and geophysics and the technique of exploration and production. His conclusions very briefly are as follows. The source beds of petroleums (other than gas) are the sapropelites (muds deposited under oxygen-free hydrogen sulphide water). Proto-petroleum is alkanic (paraffinic). The succession of evolution of petroleums is from the paraffinic through the aromatic to the naphthenic. Extensive migration across stratification is common. In oil deposits in which the heavy cyclic hydrocarbons predominate, polymerization, condensation, and ring formation have been induced by oxidation; in such deposits the specific gravity of the crude oil increases upward toward any present or past surface which has been exposed above water; and a cap of asphalt oil tends to occur above paraffine crude oils at greater depth. Geologists have been much too loose in postulating connection between oil deposits and source beds; more rigorous proof must be given each case. A high present-day content of organic material is not satisfactory evidence of such a connection.

Several rather surprising generalizations have caught the reviewer's eye in his hasty perusal of the paper: (a) "In rich deposits, oil never occurs only in a single bed but always in a series of beds one above another," and (b) "Where oil occurs in large quantity, it cuts like a spherical stock-like intrusive body up across the beds." East Texas, Van, Luling, and many other oil fields which are well known to American geologists of course contradict both generalizations.

The reviewer's views are honored by the space which Krejci-Graf takes in objecting to them. The reviewer reciprocates in believing that many of Krejci-Graf's conclusions are untenable. The reviewer, for example, can not see the tenability of the thesis of the derivation of the naphthenic petroleums from paraffinic petroleum, in view of the facts that throughout the world the older crude oils tend to be paraffinic; the paraffinic petroleums tend to be restricted to the older formations; the youngest—the Tertiary—crude oils, tend to be naphthenic and the naphthenic petroleums tend to be restricted to the Tertiary.

DONALD C. BARTON

HOUSTON, TEXAS
April, 1936

"Reports on the Geology of Cameron and Vermilion Parishes." By HENRY V. HOWE, RICHARD J. RUSSELL, JAMES H. MCGUIRT, BEN C. CRAFT, and MORTON B. STEPHENSON. *Louisiana Geol. Survey Bull. 6* (November 1, 1936). 242 pp., 10 pls., 23 figs. and bibliography.

This is another of the valuable parish reports by Howe and his associates and, like the other two reports, contains a great deal of data compiled from the files of the oil companies together with data from the files of the Conservation Commission and results of work by the staff of the Louisiana Geological Survey. This report comprises chapters on: (1) the physiography of coastal southwest Louisiana, in the main a discussion of the coastal marshes and beach ridges; (2) the salt domes and oil fields of Vermilion and Cameron parishes; (3) the salt-dome prospects in those parishes; (4) the mineral development, inclusive of shell deposits, salt, oil, and gas; (5) some micro-fossils of the *Potamides matsoni* zone of Louisiana; (6) a partial list of maps dealing with Cameron and Vermilion parishes; and (7) a valuable bibliography of 103 annotated references.

Drastic disagreement must be registered by the reviewer with much of the physiographic argument. No attempt is made in the paper to examine alternative explanations of the alleged evidences of relatively modern subsidence, for example consideration of the effect of the Inter-Coastal Canal, 150–200 feet wide and 9 feet deep, on the increased salinity and death of the cypress trees in the Lake Arthur area. The beach ridges themselves, seem to offer reasonably reliable evidence of stability of the Cameron-Vermilion parishes coast since the last post-Pleistocene, pre-modern subsidence. The reviewer disbelieves the postulated connection between the shifting of the Mississippi mouth back and forth and the formation of the successive ridges.

The bulletin should be included in the library of anyone who has to deal with Gulf Coast geology.

DONALD C. BARTON

HOUSTON, TEXAS
April 6, 1936

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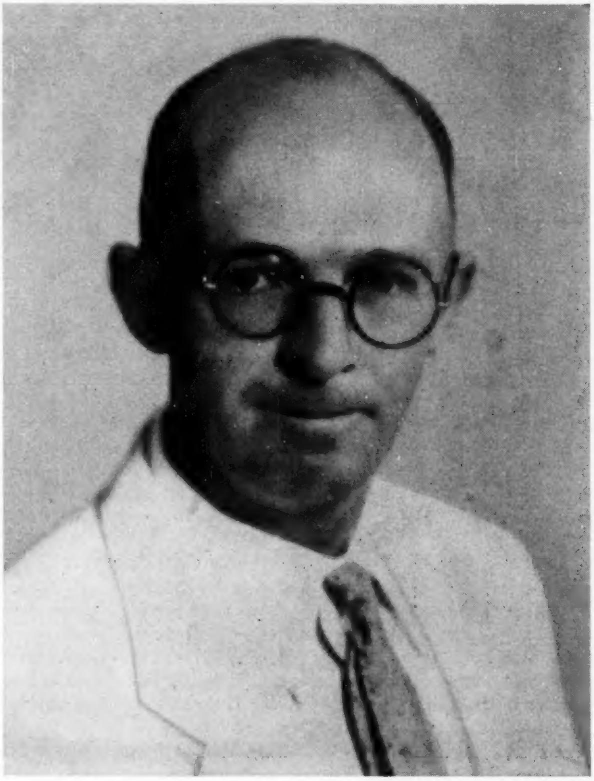
Memorial

MELVIN J. COLLINS

Melvin J. Collins was born in Creede, Colorado, August 12, 1897, and died in San Antonio, Texas, February 22, 1936. He obtained his college training from 1914 to 1920 in the University of Colorado, where he received his



Photograph by Struder

Melvin J. Collins

B. A. and M. S. degrees in geology. During his work on his Master's thesis he served as an assistant instructor in fire assaying, under Professor Crawford. While a student of the University Collins was a member of Sigma Phi Epsilon and Acacia fraternities and the Masonic Lodge of Boulder, Colorado.

On leaving the University of Colorado, Collins was employed by the Colorado Geological Survey, under Professor R. D. George, and in that connection mapped the Moffett structure. He then secured a position with Empire Gas and Fuel Company and engaged in a study of the oil shale deposits of western Colorado. In 1923 he joined the geological staff of The Texas Company, and was assigned first to southwest and then to West Texas. From 1924 to 1930 he was engaged in surface geological mapping in various portions of Texas by Marland Oil Company, Cranfill Brothers, Taylor Link Oil Company, and Douglas Oil Company. In 1930 he was employed by Big Lake Oil Company and Plymouth Oil Company in the capacity of chief geologist, which position he held until his death. He has aided in the development of deep oil in the Big Lake field of West Texas, and in the Plymouth field of San Patricio County, Texas.

Collins was active in his profession to the very day of his death, which came unexpectedly. Those who knew him look upon him as one who played an important part in the oil history of the state of Texas, and his many friends feel keenly his absence from their ranks.

ROBERT DURWARD AND KENNETH WILLSON

SAN ANTONIO, TEXAS
April, 1936

VACHEL HARRY McNUTT

Vachel Harry McNutt, member of the American Association of Petroleum Geologists, died at his home in San Antonio, Texas, on April 4, 1936. He was formerly a resident of Tulsa but had resided in San Antonio about 10 years. His immediate family consists of his wife, Mrs. Amy Shelton McNutt; a son, William Harry McNutt; a daughter, Amy Lillian; and two sisters, Mrs. J. G. Umstattd of Minneapolis, Minnesota, and Miss Lillian McNutt of Hugo, Colorado. He was born in Minerva, Kentucky, on August 18, 1888, and was of Scotch ancestry. He was educated at the Missouri School of Mines in Rolla, receiving a B. S. degree in mining engineering in 1910 when he was president of his class, an M. A. degree in 1911, and an E. M. degree in 1914. The course in petroleum geology at the school was inaugurated and taught by him until 1913. In that year the firm of Valerius, McNutt, and Hughes was organized as the first geological partnership in Tulsa, Oklahoma, and they were recognized as leaders in their profession. The spirit of leadership and pioneering of Vachel McNutt, so characteristic of his career, is exemplified in the inauguration by him of the petroleum geology course at Rolla, in the organization and work of the first company of consulting geologists in Tulsa, and in his vision and perseverance in connection with his discovery of the immensely valuable potash deposits near Carlsbad, New Mexico.

The geological partnership was dissolved about the year 1919 after which McNutt did consulting work in Tulsa for several years. He then spent some time in New Mexico and later moved to San Antonio. He is credited with the the discovery of the Russell pool in Russell County, Kansas, in 1923, as his geological recommendations led to the drilling of the discovery well by Valerius who sold his holdings while McNutt retained his interest. The year 1923 was marked by another great success for McNutt, as he made the location for the discovery well of the Artesia oil field in eastern New Mexico which was

at that time 250 miles from the nearest oil field, the Big Lake field of Reagan County, Texas.

His discovery of potash was made while continuing his pioneer work in southeastern New Mexico in 1925. He found what he called the "Twin Hills

Vachel Harry McNutt

dome" and immediately secured Government prospecting permits and made a contract for a 3,000-foot well to be drilled in Sec. 4, T. 21 S., R. 30 E. Partly because the location was so distant from any other test, McNutt insisted that samples of the cuttings be kept. However, he spent much time at the well, personally collected many of the samples and quickly recognized the polyhalite in the samples. Sylvite was also found in samples that were more minutely examined and his insistence in discussions with his associates and with Government representatives and others, that sylvite would be the more

valuable mineral, worked important results; his vision and sound judgment prevailed and led to extensive core drilling for the richer sylvite. Very valuable deposits, superior to those in Germany, were located, The first core test, commenced April 14, 1926, was completed in July, 1926. The Federal Potash Exploration Act was approved in June, 1926, and late in July the first Government drilling locations were made in New Mexico.

The drilling and coring operations of McNutt and associates resulted in the development by the United States Potash Company of the first potash mine in the western hemisphere. To few geologists come the honors of such a series of business achievements as those of Vachel McNutt. His reticence in not affirming his responsibility for the discovery of commerical potash although aware of counter insinuations of some organizations and individuals was characteristic of this modest person. His achievement which led to inaugurating a new industry in the western hemisphere was regarded as of such outstanding importance that it was proclaimed in a speech in the United States Senate by Senator Carl A. Hatch of New Mexico on April 14, 1934, printed in the *Congressional Record*. In his speech Senator Hatch called attention to the discovery of potash by McNutt and the part played by McNutt and his associates in the project "because they displayed great courage and that pioneering spirit which has been responsible for the development of the industries and vast resources of America." This well deserved publicity, though somewhat late, constitutes a correct and proper record of the results of the efforts of McNutt in "bringing us independence from foreign domination over the supply of an essential commodity." The development of the new industry in this country is having far reaching effects and time will crystallize gratitude to Vachel McNutt in appreciation of his excellent work.

In more recent years McNutt was interested in metal mining and in ranching. He was the owner of the historical Peter Gallagher Ranch, a large tract in the hill country 25 miles from San Antonio. He was a member of the American Institute of Mining and Metallurgical Engineers, the American Association of Petroleum Geologists, and the San Antonio Geological Society. He was also a member of the Board of the Alumni Association of the Missouri School of Mines. In 1924 he published, in collaboration with Conrad Lambert, a book titled *The First Principles of the Oil Business*. McNutt reasoned analytically and possessed to a marked degree the desirable combination of technical and business ability. His naturally keen discernment in business affairs was a great asset and his consistent success in business ventures gave promise of still greater attainments. He possessed a sparkling and delighting humor which made him a charming companion and his untimely passing is so profoundly regretted by all who knew him that words are, at best, only inadequate expressions of their feeling of great loss.

E. H. Finch

San Antonio, Texas
April 15, 1936

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

WILLARD M. PAYNE is again with The California Company, 2900 Smith-Young Tower, San Antonio, Texas.

E. FLOYD MILLER, chief geologist for the Bay Oil Corporation of Houston, has been transferred to Tulsa.

WATSON H. MONROE, junior geologist of the United States Geological Survey, who prepared *Bulletin 831-A* on the Jackson gas field, has been completing his research work in that area.

C. A. RUSSELL, has joined the Pan American Production Company, Houston, as general superintendent of production. He was vice-president of the Republic Production Company, in charge of the land, geophysical, and geological departments.

K. A. (GUS) SCHMIDT, geologist for the Tide Water Oil Company, has been transferred from Palestine, Texas, to Shreveport, Louisiana. Schmidt was one of the principals in locating the Long Lake and Cayuga fields in Anderson County, Texas.

HERMAN W. WEDDLE, paleontologist, has been transferred from the Standard Oil Company of California, Los Angeles, to The California Company, Smith-Young Tower, San Antonio, Texas.

RICHARD N. NELSON has changed his address from 1102 Standard Oil Building, San Francisco, California, to Nederlandsche Pac. Petr. Mij., Batavia-Centrum, Java, Dutch East Indies.

The Section on Geology and Geography of the American Association for the Advancement of Science is holding meetings in Rochester, New York, on June 17 and 18. Papers include problems of New York state geology, and correlation with Pennsylvania strata. Among those presenting papers are: MARSHALL KAY, WILMOT BRADLEY, G. H. CHADWICK, N. C. DALE, ALFRED HAWKINS, J. R. SANFORD, F. M. SWARTZ, BRADFORD WILLARD, and other members of the staffs of Syracuse and Cornell Universities. KIRTLEY F. MATHER is secretary of Section E.

CHARLES GILL MORGAN, formerly with the Seismograph Service Corporation, Tulsa, is now with the Research Laboratory Service, Inc., 164 North Hill, Pasadena, California.

R. G. MOSS of the Phillips Petroleum Company, has been transferred from Wichita, Kansas, to 1045 Milam Building, San Antonio, Texas.

FRANK R. KITTREDGE has changed his address from Shawnee, Oklahoma, to 907 East 13th Street, Cameron, Texas.

The Field Conference of Pennsylvania Geologists and the New York State Geological Association held a joint excursion in the Pennsylvania anthracite region from May 22 to 24.

D. R. Snow, vice-president in charge of production and geology for the Barnsdall Corporation, has been made a director of the company to succeed George D. Locke.

Raymond S. Hunt, formerly in charge of Michigan land and producing divisions, Mt. Pleasant, Michigan, resigned to accept a position as geologist of the newly-organized Cryden Oil Company of Mt. Pleasant. Clyde Cantrell has been elected president, Allen Gray, vice-president, and Haswell W. Grant, secretary.

Bert S. Ridgeway, formerly assistant district geologist for the Empire Oil and Refining Company, Wichita, Kansas, has succeeded R. S. Hunt at Mt. Pleasant and is now in charge of the district office of the Dokenva Gas Corporation, a subsidiary of Cities Service Oil Company. His address will be Box 149, Mt. Pleasant, Michigan.

C. E. Sutton of the Pure Oil Company, Houston, was elected chairman of the advisory committee at the spring meeting of the Southwestern District, American Petroleum Institute, Division of Production, held in Shreveport, April 9–10. R. S. McFarland, Seaboard Oil Company, Dallas, Texas; F. C. Sealey, Texas Company, Houston; and John R. Suman, Humble Oil and Refining Company, Houston, are some of the members of the committee.

George Sawtelle, president and general manager of the Kirby Petroleum Company, was the principal speaker at the weekly meeting of the Houston Geological Society, April 16, discussing salt-dome statistics.

Wallace Lee of the United States Geological Survey at Wichita, Kansas, read a paper on "The Mississippian of Southeastern Kansas," at the meeting of the Kansas Geological Society of Wichita, April 15. Lee's study is the result of a joint project of the United States Geological Survey and the Kansas State Geological Survey and will be continued at least another year.

P. Charrin, assistant manager of the Schlumberger Well Surveying Company, is located in the Esperson Building, Houston, Texas.

J. J. Zorichak, production engineer for the Stanolind Oil and Gas Company, discussed "Water Control in Pumping Wells," at the meeting of the Tulsa Geological Society held on April 20.

Robert M. Whiteside, who recently resigned from the geological department of the Shell Petroleum Corporation, has joined the W. A. Delaney Interests and will make his headquarters in Ada, Oklahoma.

P. F. Martyn, chief geologist, Houston Oil Company, Houston, Texas, addressed the San Antonio Geological Society, April 20, and the Dallas Petroleum Geologists, April 27, on the Refugio field in southwest Texas.

John Emery Adams, district geologist for The California Company at Midland, addressed the West Texas Geological Society at Midland on "An Oil Pool of Open Reservoir Type." The Society held a field trip to the Marathon Basin in Brewster County, May 9 and 10, to study the older Paleozoics.

L. G. PUTNAM, a California geologist, for the last two years employed by the Inyaminga Petr., Ltd., Portuguese East Africa, of which company D. DALE CONDIT is chief geologist, lost his life in an air plane crash.

KARL ETIENNE YOUNG, 32, geologist and independent oil operator of Houston, died April 20 at a hospital in Houston. His death was the result of an injury sustained April 1 when an air compressor exploded.

HAROLD O. SMEDLEY has recently been elected secretary-treasurer of the Kansas Geological Society to fill the vacancy created by the resignation of B. S. Ridgeway who has recently been transferred to Mt. Pleasant, Michigan.

BETTY KELLETT NADEAU, formerly micro-paleontologist with Amerada Petroleum Corporation, is now doing consulting work and is located at the Edgington apartments, Wichita, Kansas.

RAY WHORTAN, president of the Kansas Geological Society, who has been associated with Tom Johnson, has severed his connections and now is in business for himself.

ELLEN POSEY, paleontologist with the Empire Oil and Refining Company in the Bartlesville office is spending a few weeks in the Kansas District office of the company at Wichita, Kansas.

GLENN WOOLLEY, until recently geologist with the Derby Oil Company, is now in charge of the geological operations of the Franco-Central Oil Company, with offices in the Fourth National Bank Building, Wichita, Kansas.

KEITH RATHBURN and GEORGE KLEIN, recently graduated from the University of Nebraska, have been added to the geological staff of the Oklahoma-Kansas Division of the Continental Oil Company at Ponca City, Oklahoma.

GEORGE E. TAYLOR, geologist with the Continental Oil Company, is temporarily stationed at McPherson, Kansas.

T. WAYLAND VAUGHAN, director of the Scripps Institution of Oceanography, had conferred upon him the doctorate of laws of the University of California on the occasion of the Charter Day exercises.

CARLTON D. SPEED, JR., has organized the Speed Oil Company and opened offices in the Second National Bank Building, Houston, where he will make appraisals, geological surveys, and lease and drill.

W. C. MENDENHALL, director of the United States Geological Survey, has been elected president of the Geological Society of America for 1936. W. E. WRATHER and GEORGE D. LOUDERBACK were elected vice-presidents.

ROLAND F. BEERS has resigned as vice-president of the Geophysical Service, Inc., and is now president of The Geotechnical Corporation, 902 Tower Petroleum Building, Dallas, Texas. W. W. Newton is an associate in the new corporation.

H. F. MOSES, of Denver, is now with the Michigan division of the Carter Oil Company at Mt. Pleasant, Michigan.

S. H. WILLISTON, economic geologist of Aberdeen, Washington, has taken an option on the Horse Heaven mercury mine near Ashwood in north-central Oregon, after an examination of the property made jointly with MILNOR ROBERTS, of Seattle.

ROBERT B. MORAN, geologist and engineer, of Los Angeles, is president of the Casualidad Syndicate, which is planning a small mill for the high-grade gold and silver ore that the company is mining at Durango City, Mexico.

HEWLETT A. RUSSELL, formerly of San Francisco, California, is now with The California Company, Midland, Texas.

WADE H. HADLEY, JR., formerly at Louisiana State University, Baton Rouge, is now with The Pure Oil Company, Geological Department, Fort Worth, Texas.

E. G. LEONARDON, vice-president of the Schlumberger Well Surveying Corporation, Houston, Texas, announces that suit for infringement of certain of its United States patents was commenced against the Geoanalyzer Corporation, Long Beach, California, March 24, 1936.

E. HAZEN WOODS, recently with the Superior Oil Company, is now employed by the Sinclair Prairie Oil Company, Midland, Texas.

W. W. ORCUTT, vice-president of the Union Oil Company, Los Angeles, and organizer of the first geological department on the Pacific Coast, was the guest speaker at a recent monthly meeting of the Historical Society of Southern California.

CLENON HEMSELL, geologist and land man for the Cabot Carbon Company, has been transferred from Amarillo, Texas, to Kansas on a temporary assignment.

GILBERT W. NOBLE, who has recently completed his thesis on fuel economics, is a candidate for the degree of Doctor of Science in Mining Engineering at the Massachusetts Institute of Technology.

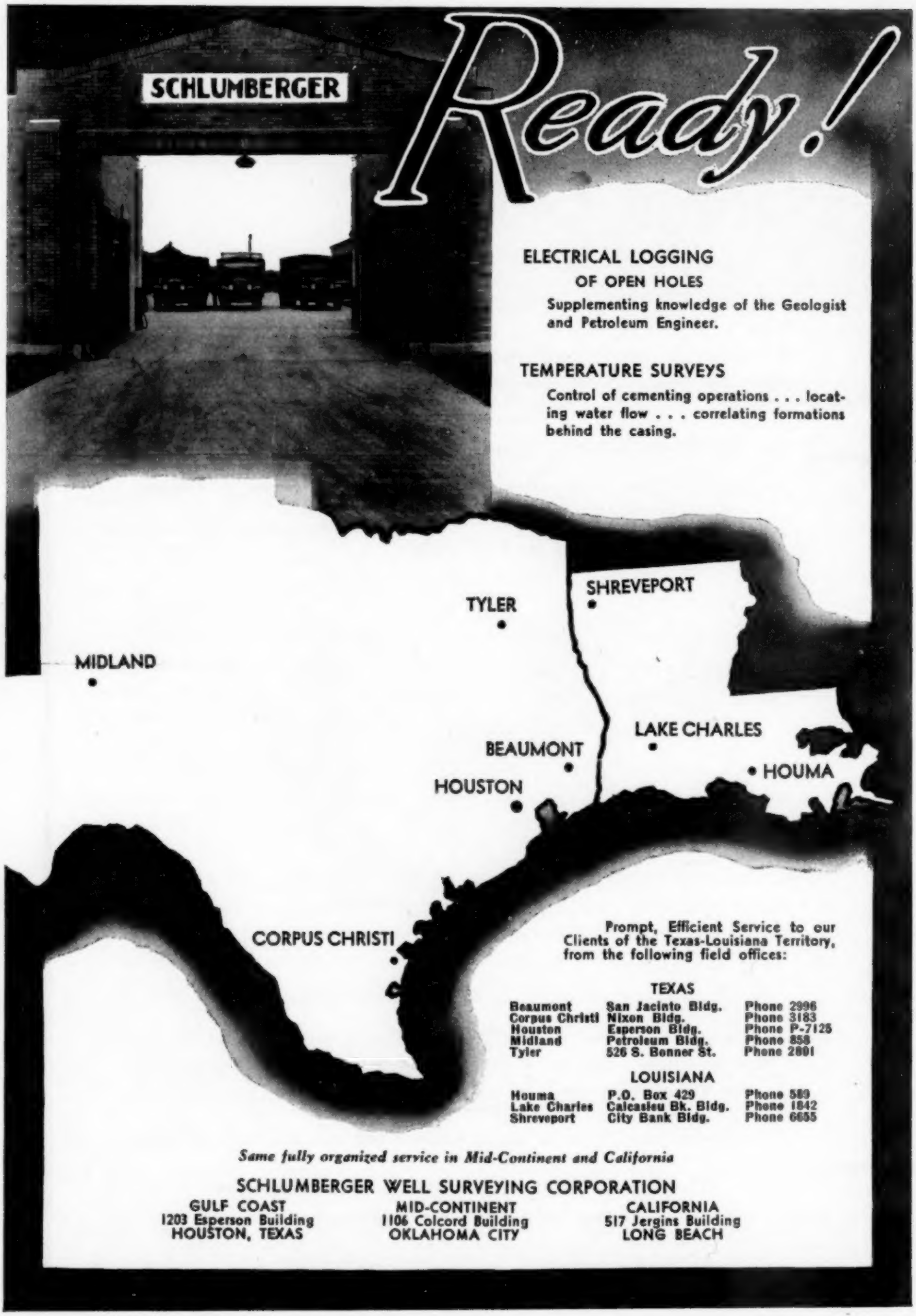
W. E. WRATHER of Dallas, was a luncheon guest and gave a short talk at the weekly meeting of the San Antonio Geological Society, April 20.

RAYMOND M. LARSEN of the Oil and Gas Leasing Division, United States Geological Survey, Thermopolis, Wyoming, is in Washington, D. C., for about three months on temporary work in connection with unit plans.

RICHARD B. RUTLEDGE, president of the Tulsa Geological Society, addressed the society at its meeting in the Tulsa Building, May 4, on the "Cunningham Pool, Kingman County, Kansas."

E. H. STEVENS spoke on "Some Problems of the Heart Mountain Thrust Near Cody, Wyoming" at the meeting of the Rocky Mountain Association of Petroleum Geologists, Denver, Colorado, May 4.

HUGH A. STEWART spoke on "Some Ideas on Unitization" at the meeting of the Rocky Mountain Association of Petroleum Geologists, Denver, Colorado, April 20.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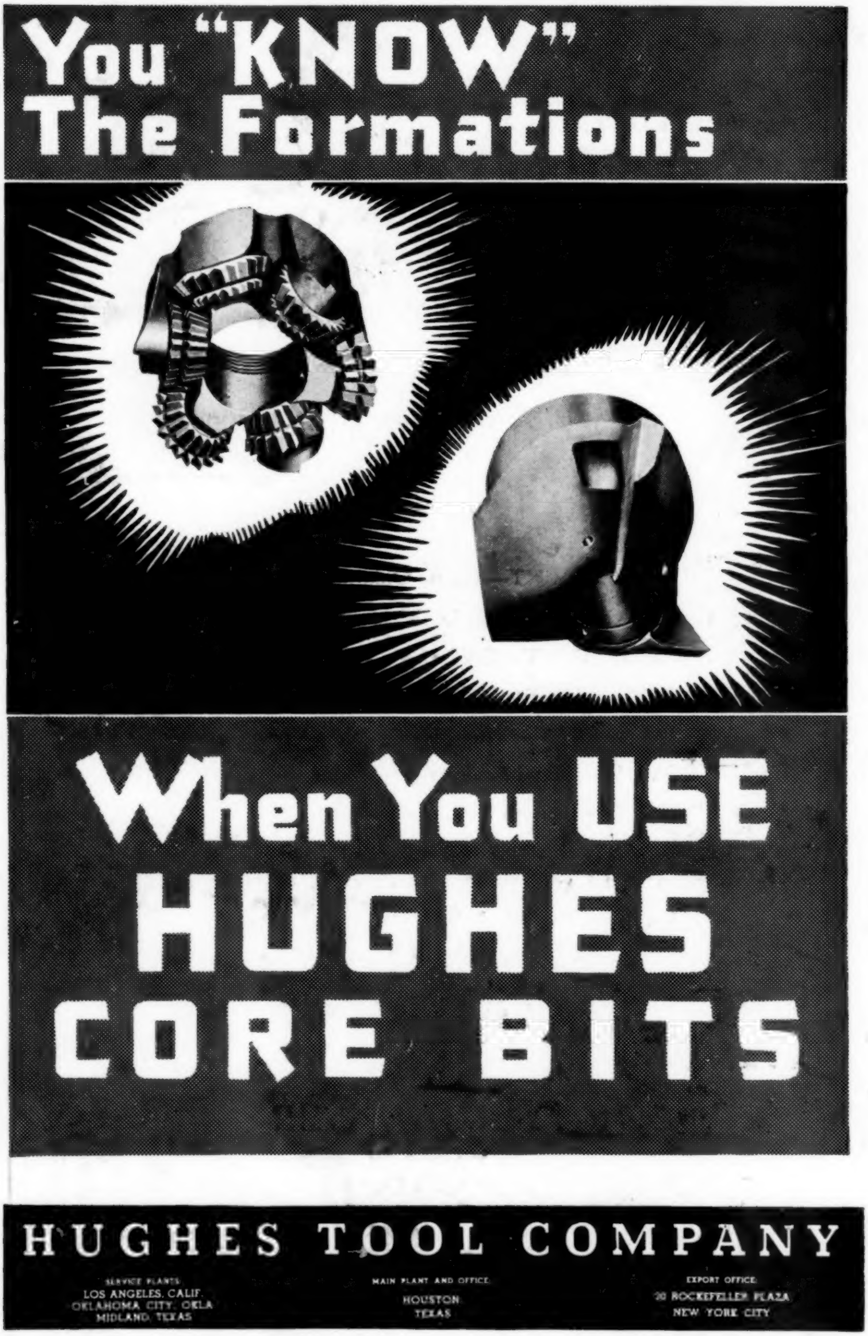
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